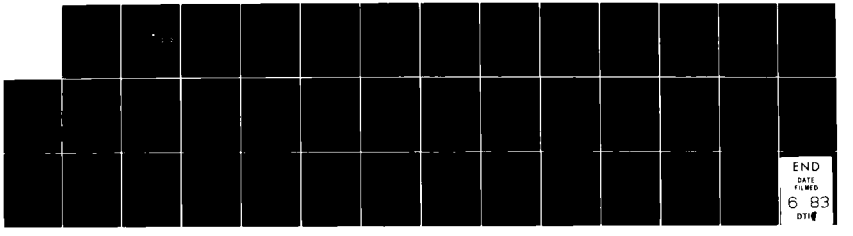
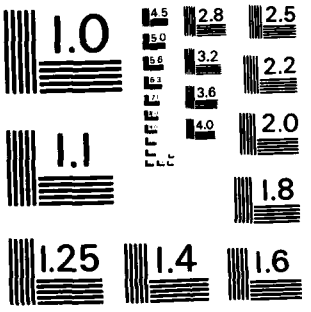
AD-A127 531 VEHICULAR INTERCEPT GEOMETRY(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA J B TYSVER DEC 82 NPS55-82-036 1/1

UNCLASSIFIED F/G 15/7 NL



END
DATE FILMED
6 83
DTIC



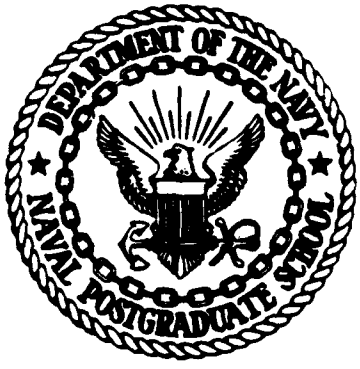
(2)



NPS55-82-036

# NAVAL POSTGRADUATE SCHOOL

## Monterey, California






# VEHICULAR INTERCEPT GEOMETRY

by

J. B. Tysver

December 1982



Prepared for: Research and Engineering Department
Naval Undersea Warfare Engineering Station
Keyport, Washington 93945

NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA

Rear Admiral J. J. Ekelund
Superintendent

D. A. Schrady
Provost

The work herein was supported in part by funds provided by the Naval Undersea Warfare Engineering Station, Keyport, Washington. Reproduction of all or part of this report is authorized.

This report was prepared by:

J. B. Tysver

J. B. Tysver, Associate Professor
Department of Operations Research

Reviewed by:

Alan R. Washburn, Chairman
Department of Operations Research

Released by:

William M. Tolles
William M. Tolles
Dean of Research

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|
| 1. REPORT NUMBER: NPS55-82-036 | 2. GOVT ACCESSION NO.: AD-A127531 |
| | 3. RECIPIENT'S CATALOG NUMBER: |
| 4. TITLE (and Subtitle): VEHICULAR INTERCEPT GEOMETRY | 5. TYPE OF REPORT & PERIOD COVERED: Technical |
| | 6. PERFORMING ORG. REPORT NUMBER: |
| 7. AUTHOR(s): J. Bryce Tysver | 8. CONTRACT OR GRANT NUMBER(s): |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS: Naval Postgraduate School, Monterey, CA 93940 | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: N0025382WR70002 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS: Research and Engineering Department, Naval Undersea Warfare Engineering Station, Keyport, WA 98345 | 12. REPORT DATE: December 1982<br>13. NUMBER OF PAGES: 33 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) | 15. SECURITY CLASS. (of this report): Unclassified<br>15a. DECLASSIFICATION/DOWNGRADING SCHEDULE: |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Geometry Intercept
Intercept
Attack Angle
Miss Distance
Look Angle
Missing Points
Outliers

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the potential use of 3-D data at NUWES on trial runs to provide information on the geometry of two vehicles in the vicinity of intercept. Smoothing of data segments provides velocity components as well as smoothed estimates of vehicle locations. Analysis of this smoothed data can be analyzed to establish (1) distance between vehicles, (2) vehicular heading directional angles, (3) look angle for attack vehicle, (4) attack angle, (5) projected intercept point and time, (6) projected miss distance, and

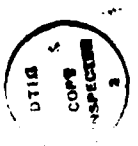
DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

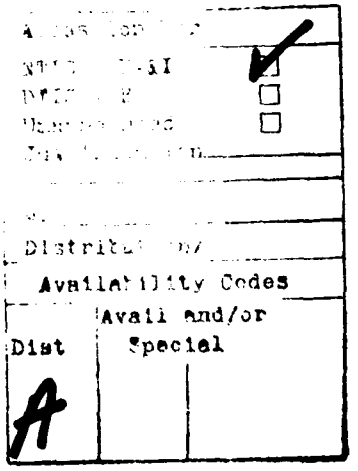
UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

VEHICULAR INTERCEPT GEOMETRY


## ABSTRACT

This report presents the potential use of 3-D data at NUWES on trial runs to provide information on the geometry of two vehicles in the vicinity of intercept. Smoothing of data segments provides velocity components as well as smoothed estimates of vehicle locations. Analysis of this smoothed data can be analyzed to establish (1) distance between vehicles, (2) vehicular heading, directional angles, (3) look angle for attack vehicle, (4) attack angle, (5) projected intercept point and time, (6) projected miss distance, and (7) actual miss distance.

# VEHICULAR INTERCEPT GEOMETRY

by

J. B. Tysver
Associate Professor
Operations Research Department
Naval Postgraduate School
Monterey, California

December 1982

# VEHICULAR INTERCEPT GEOMETRY

## I. INTRODUCTION

3-D data provided to Proof and Test by Instrumentation is of the form $(t_i, x_i, y_i, z_i)$ for a sequence of equally spaced times. When a trial run involves an attack by one vehicle (A) on another vehicle (B), the geometry in the vicinity of intercept is of special interest. Intercept geometry is examined in this report.

The data received by Proof and Test is assumed to be smoothed using the 7-Point Least-Squares Polynomial procedure as described in Reference 1. The smoothed values of $x_i, y_i,$ and $z_i$ are considered the best estimates of the actual locations of the vehicles at any time. In addition, the smoothing provides information on the direction and velocity of each vehicle.

The trial run (labeled Trial 2) used for illustration in this study consisted of data with all $y$ coordinates being negative. In addition, the general direction of the vehicular paths and of the vehicles in the intercept portions of the trial were in the negative $y$ direction. For this reason the reference direction from which the vehicular directions were measured was taken to be the negative $y$ direction. A general sketch of the horizontal geometry in the vicinity of intercept is shown in Figure 1.

Mathematical analysis of the intercept geometry is described in Section II and illustrated in Section III.

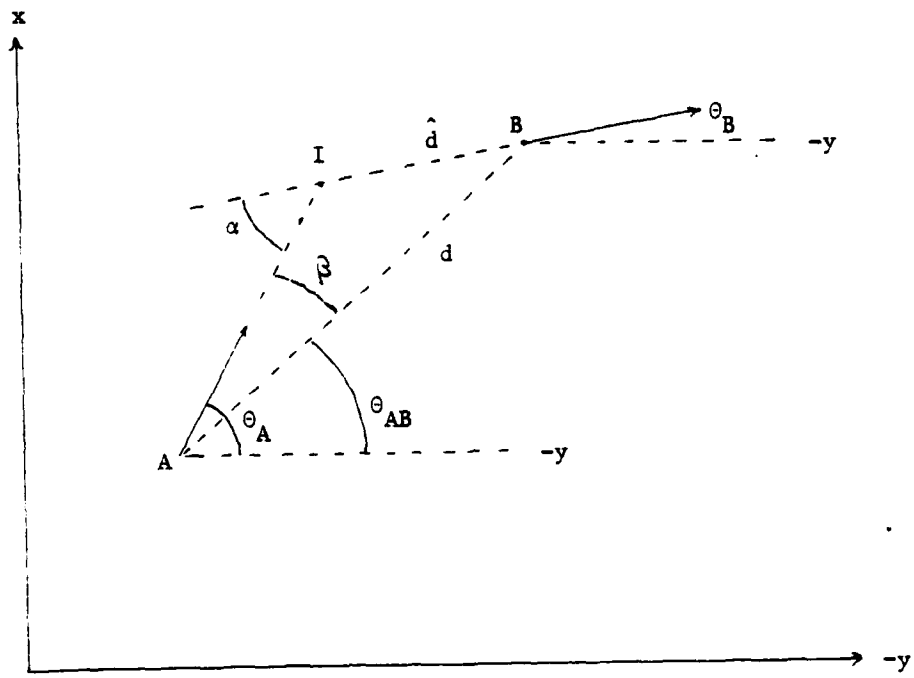



Figure 1. Horizontal Geometry for Projected Intercept

## II. GEOMETRY OF INTERCEPT

### A. Analysis of Horizontal Components

There are several aspects of an intercept that are of particular concern. The horizontal components $(x,y)$ were considered first as described below.

1. Distance between vehicles

The horizontal distance between vehicles A and B at any time $t_i$ is

$$d_i = [(x_{Ai} - X_{Bi})^2 + (y_{Ai} - y_{Bi})^2]^{1/2} .$$

2. In addition to providing smoothed values for vehicular coordinates at any time, the smoothing procedure provides estimates of the vehicles velocity components. These are the coefficients ($b_{x1}$ and $b_{y1}$) of the first order term in the smoothing polynomials. (The time unit for these components is the time interval between observations and must be converted if estimates of actual velocities ($\dot{x}_i$ and $\dot{y}_i$) are desired.)

The horizontal components of the heading direction angles of the two vehicles at time $t_i$ are

$$\Theta_{Ai} = \arctan \frac{\dot{x}_{Ai}}{-\dot{y}_{Ai}} = \arctan \frac{b_{Axli}}{-b_{Ayli}} ,$$

$$\Theta_{Bi} = \arctan \frac{\dot{x}_{Bi}}{-\dot{y}_{Bi}} = \arctan \frac{b_{Bxli}}{-b_{Byli}}$$

3. Horizontal Look Angle

The horizontal Line-of-Sight Angle to vehicle B from vehicle A is

$$\Theta_{AB} = \arctan \frac{x_B - x_A}{(-y_B) - (-y_A)} .$$

The horizontal Look Angle is the angle between the direction vehicle A is headed and the direction from vehicle A to vehicle B . This angle is

$$\beta = \Theta_A - \Theta_{AB} .$$

Both angles are shown in Figure 1.

4. Attack Angle

The horizontal Attack Angle is the difference in the horizontal directions of the two vehicles, i.e.,

$$\alpha = \Theta_A - \Theta_B .$$

This is also shown in Figure 1.

5. Projected Intercept Point

Assuming instantaneous linear paths for both vehicles, the point at which these two paths intercept (I) has the horizontal components

$$y_I = \frac{(x_B - x_A) + y_A \tan \Theta_A - y_B \tan \Theta_B}{\tan \Theta_A - \tan \Theta_B} ,$$

$$x_I = x_A + (y_I - y_A) \tan \Theta_A .$$

Again, the Projected Intercept Point is shown in Figure 1.

6. Projected Miss Distance

The horizontal component of the Projected Miss Distance is the distance between points I and B, i.e.,

$$\hat{d} = [(x_B - x_I)^2 + (y_B - y_I)^2]^{1/2} .$$

7. Actual Miss Distance

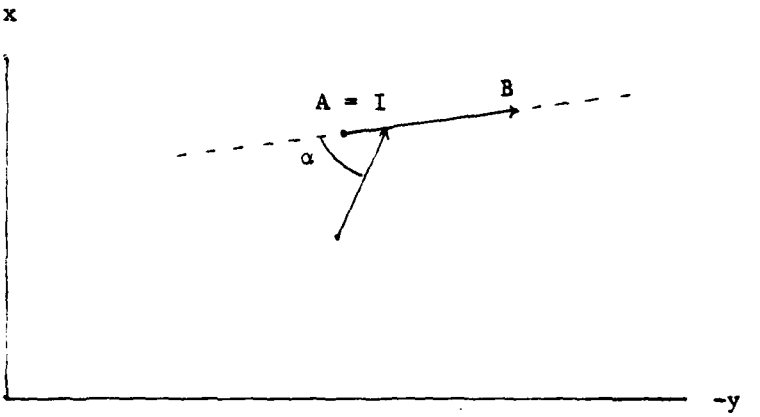
The Actual Miss Distance and the Attack Angle are of importance in damage assessment. For purposes of illustration, it is assumed that the points A and B (point sources for the position location system) are located on the noses of the vehicles and that vehicle B has length c . (Note that determination of the point and angle of impact may require interpolation between observational times.) The point and angle of impact, if it occurs are sketched in Figure 2a. The actual impact point is at a distance $d^* = \hat{d}$ . Figure 2b shows the situation where the attack vehicle (A) passes behind the target vehicle (B). The actual Miss Distance is

$$d^* = (\hat{d} - c) .$$

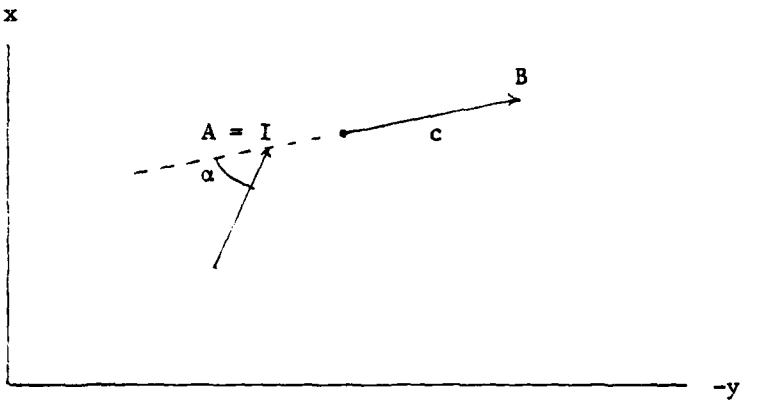
Figure 2c shows the situation when the attack vehicle crosses ahead of the target vehicle. The actual miss distance is

$$d^* = \hat{d} .$$

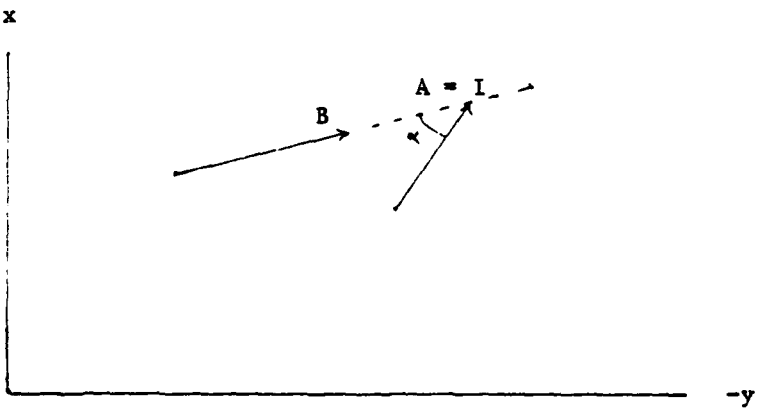
When the two vehicular paths do not intersect, the determination of actual miss distance requires further examination.




2a. Intercept occurs at A = I with $d^* = \hat{d}$




2b. Miss with $d^* = -(\hat{d}-c)$




2c. Miss with $d^* = \hat{d}$

**Figure 2. Actual Horizontal Miss Distance**

II B. Analysis of Vertical Components

This analysis was not completed during the research period covered by this report.

## III. ILLUSTRATION

### A. General Description of Trial Run

3-D data from a trial run at NUWES (the investigator's Trial #2) will be used for illustration of the concepts presented in Section II. The paths of the two vehicles in the horizontal plane are shown in Figure 3a and the vertical components in Figure 3b. Three attacks occurred in this trial. These are labeled 2I1, 2I2, and 2I3 and occur approximately at times t = 2130, 2201, and 2270, respectively.

For each of these intercept attempts a sequence of plots was produced. These are discussed in the following sections and are shown in Figures 4, 5, and 6. Each figure is started by a magnified plot of the vehicular paths in the x,y plane (labeled 2IH) and of the vertical path (2IZ). These are followed by a sequence of plots of the geometry of the horizontal situations at observational times in the vicinity of the attempted intercept. Actual intercept did not occur in any of the three attacks.

The vertical components of the attacks have not been examined in any detail. It should be noted, however, that the attacks were aborted in the vertical direction while the appear to be continued in the horizontal plane. This is presented in Table I.

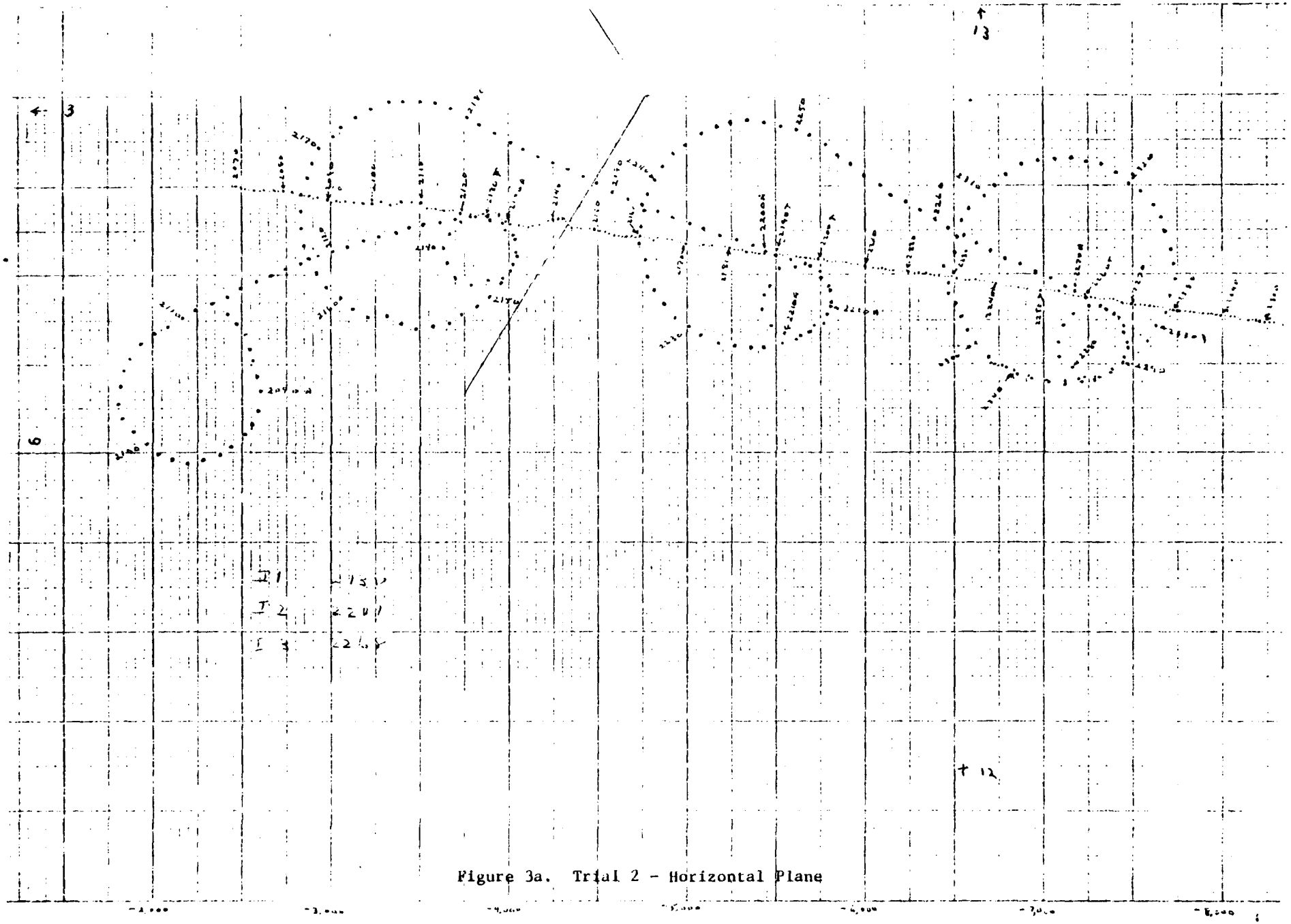


Figure 3a. Trial 2 - Horizontal Plane

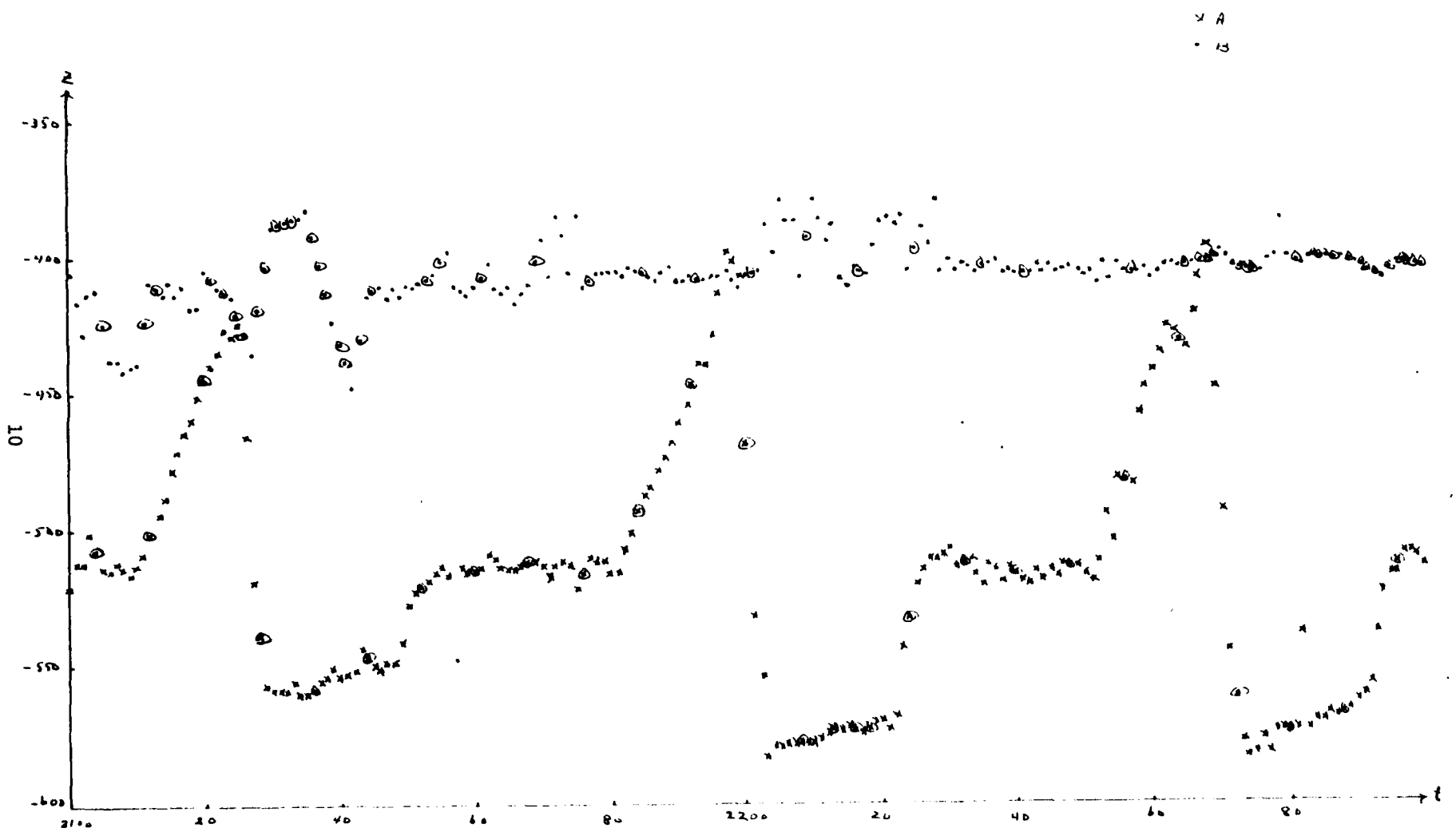



Figure 3b. Trial 2 - Vertical Components

TABLE 1. Differences between Horizontal and Vertical Attacks

| Event | Approximate Time | Vertical Distance between vehicles | Horizontal Distance between vehicles |
|---|---|---|---|
| Abortion of Attack #1 in vertical plane | 2125 | 3.1 | 425.5 |
| Discontinuance of Attack #1 in horizontal plane | 2131 | 171.1 | 47.0 |
| Abortion of Attack #2 in vertical plane | 2196 | 9.0 | 562.1 |
| Discontinuance of Attack #2 in horizontal plane | 2202 | 148.0 | 204.0 |
| Abortion of Attack #3 in vertical plane | 2268 | 5.9 | 431.5 |
| Discontinuance of Attack #3 in horizontal plane | 2272 | 158.1 | 215.5 |

B. First Attack (2I1)

This attack was initiated when vehicle A (the attack vehicle) detected vehicle B (the target vehicle) at approximately time t = 2110 (see Fig. 3a). The portion of this attack in the vicinity of intercept is shown in Figure 4a (horizontal components, 2I1H) and Figure 4b (vertical component, 2I1Z). The geometry of the vehicles in the horizontal plane at times in this vicinity are shown in Figures 4c-j. Actual intercept was not achieved since the attack appears to have been aborted in the z component at about time t = 2125 while the attack vehicle was still a substantial distance from the target vehicle in the horizontal plane.

It would appear that the attack was continued in the horizontal plane until about time t = 2131 (see Figures 4i and 4j) when the attack vehicles did not intersect. The closest approach of the attack vehicle occurred at about time 2132 after the attack vehicle had discontinued the attack.

It should be noted that there are many missing observations (circled points) particularly in the path of the target vehicle. These are most frequent after the attack has been discontinued and thus may not present a serious problem.

There are also two potential outliers (boxed points) in the z component of the path of the attack vehicle. The first of these is at time t = 2125 and possibly indicated a change of path (abortion of attack) rather than an actual outlier. These potential outliers and nearby missing points are worthy of further examination and will be treated in a separate report.

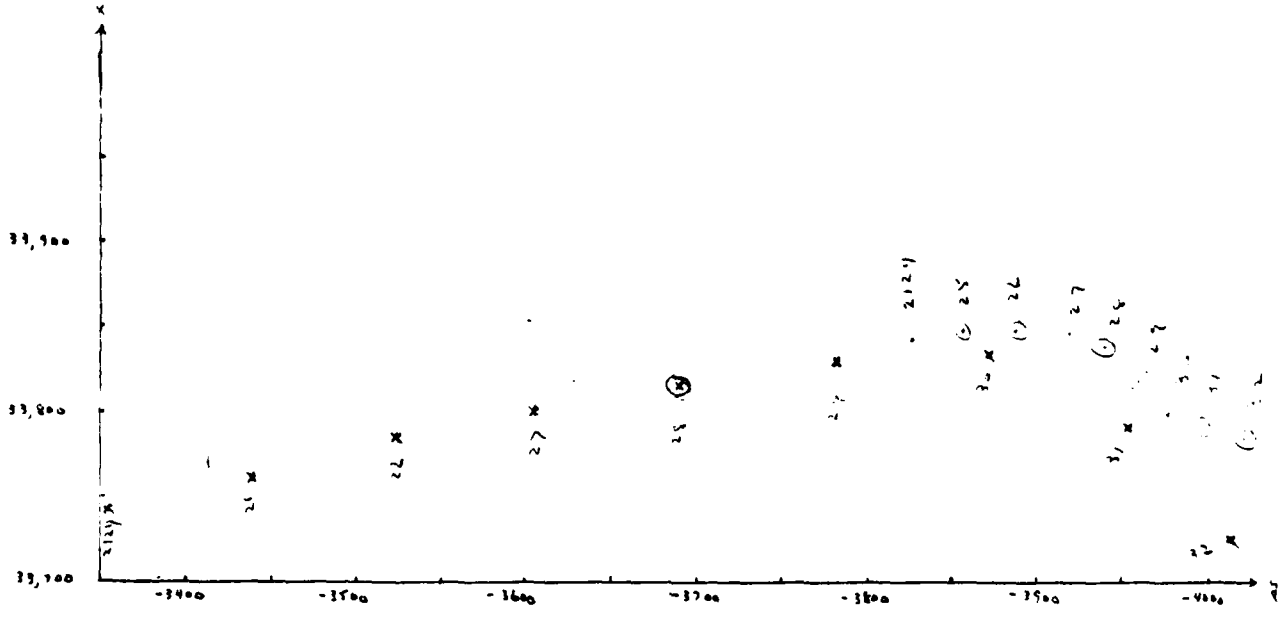


Figure 4a. 2I1H

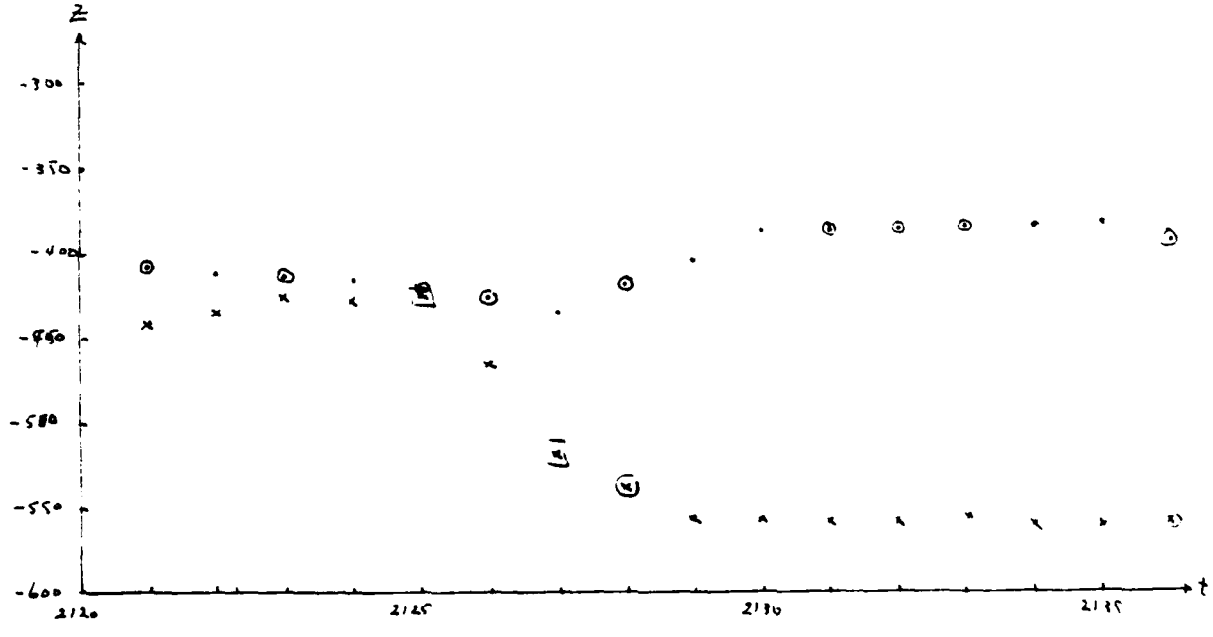


Figure 4b. 2I1Z

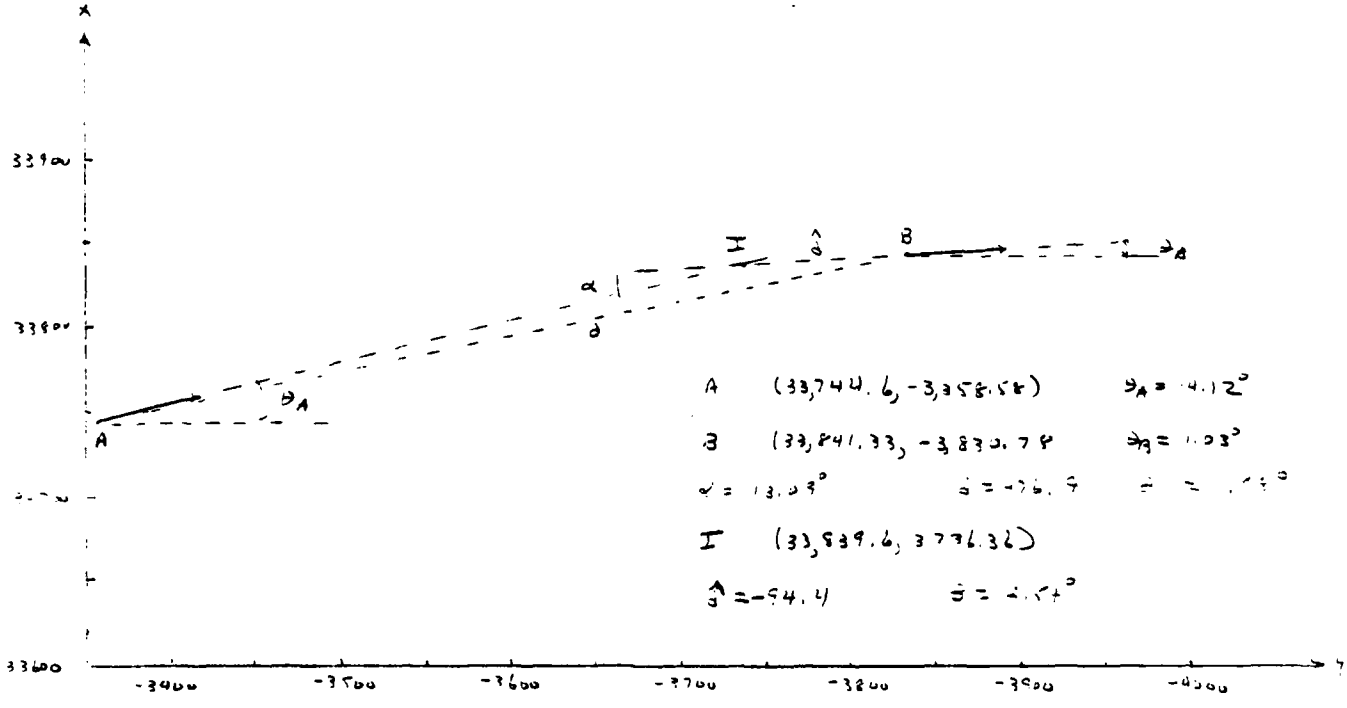



Figure 4c. 211H, t = 2124

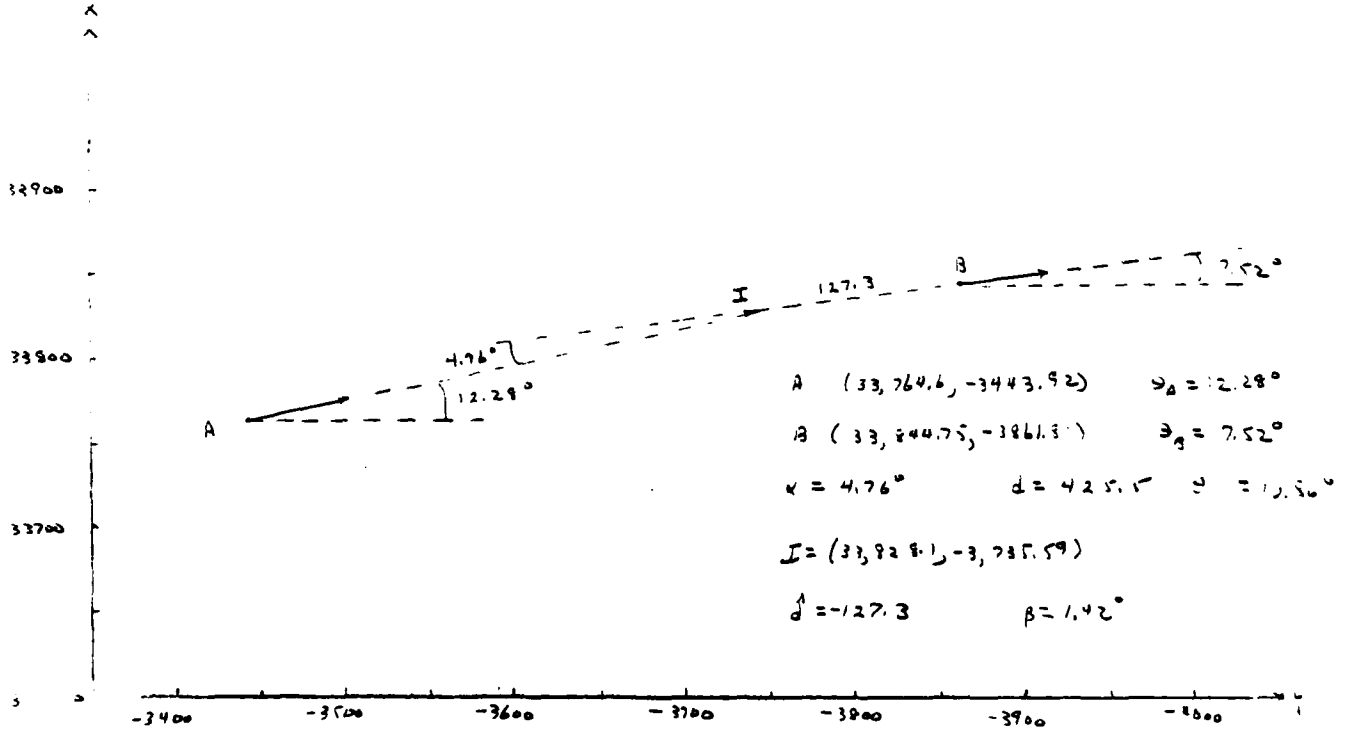



Figure 4d. 211H, t = 2125

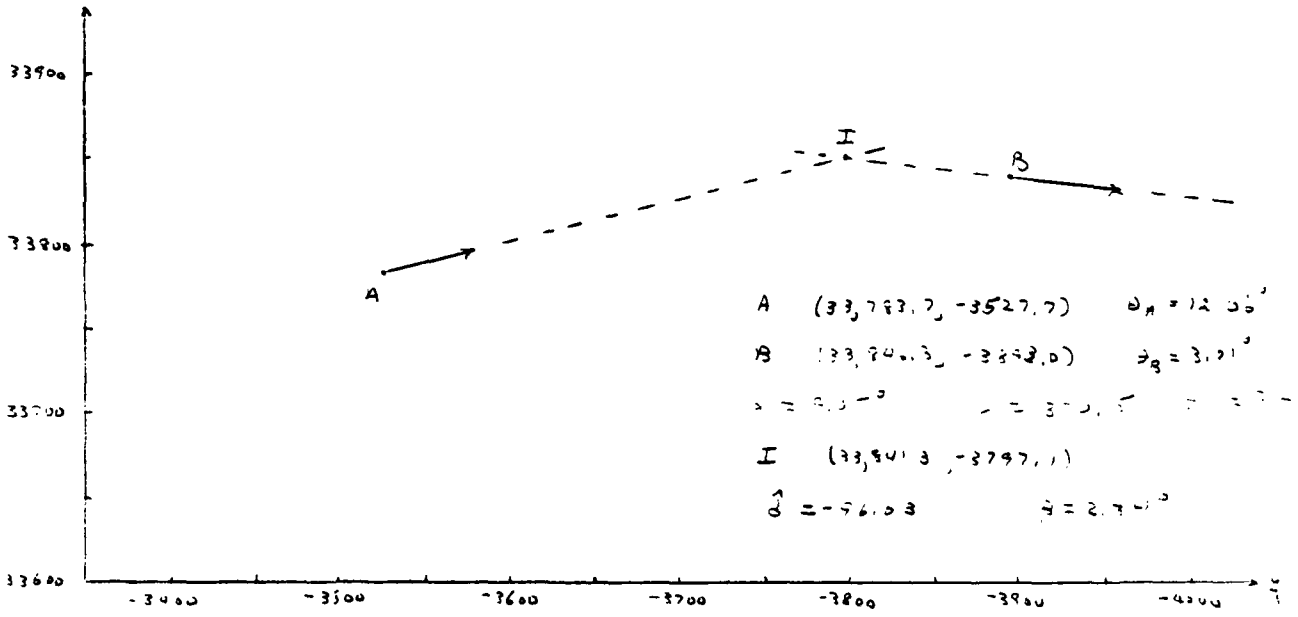



Figure 4e. 2I1H, 2126

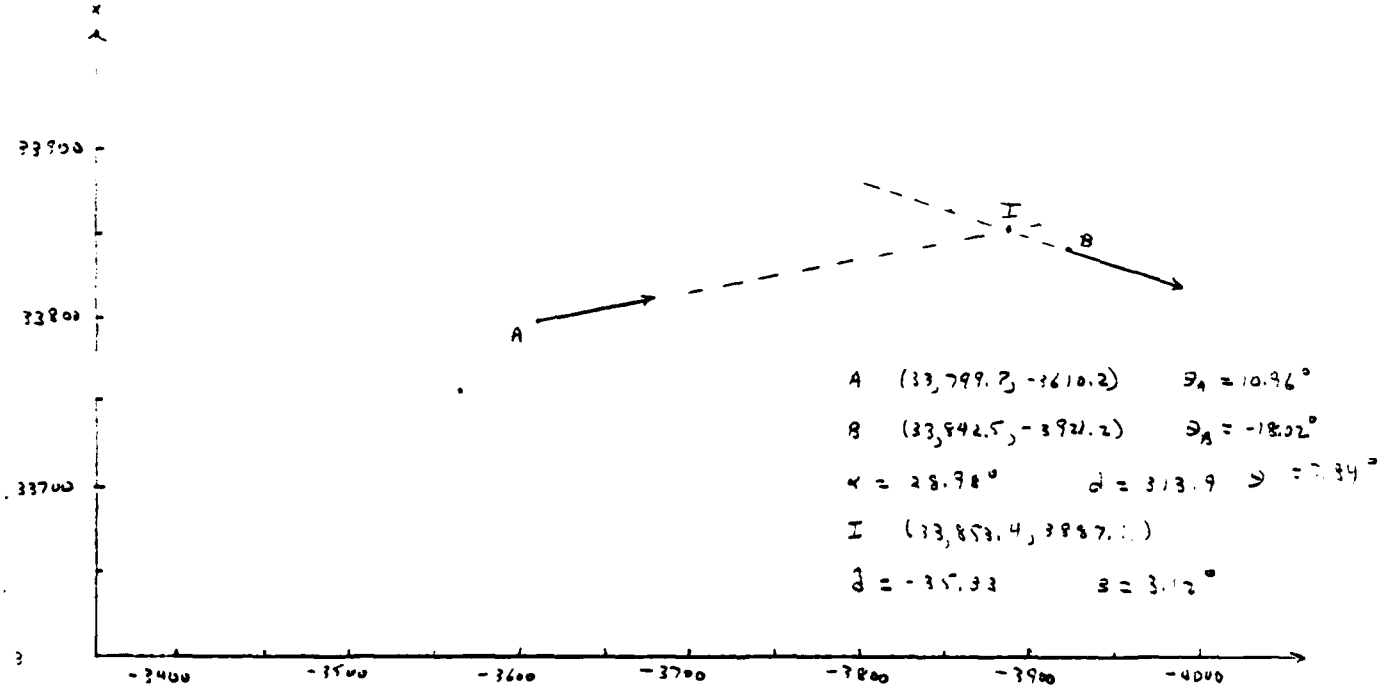



Figure 4f. 2I1H, 2127

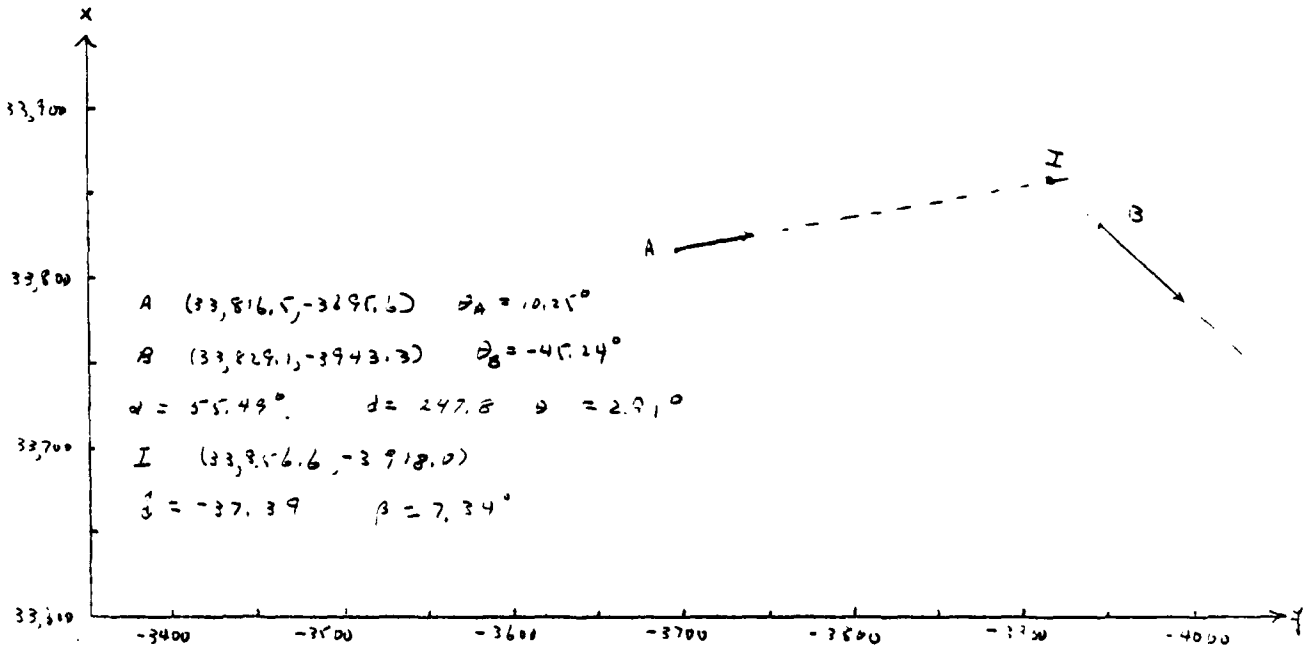



Figure 4g. 2I1H, 2128

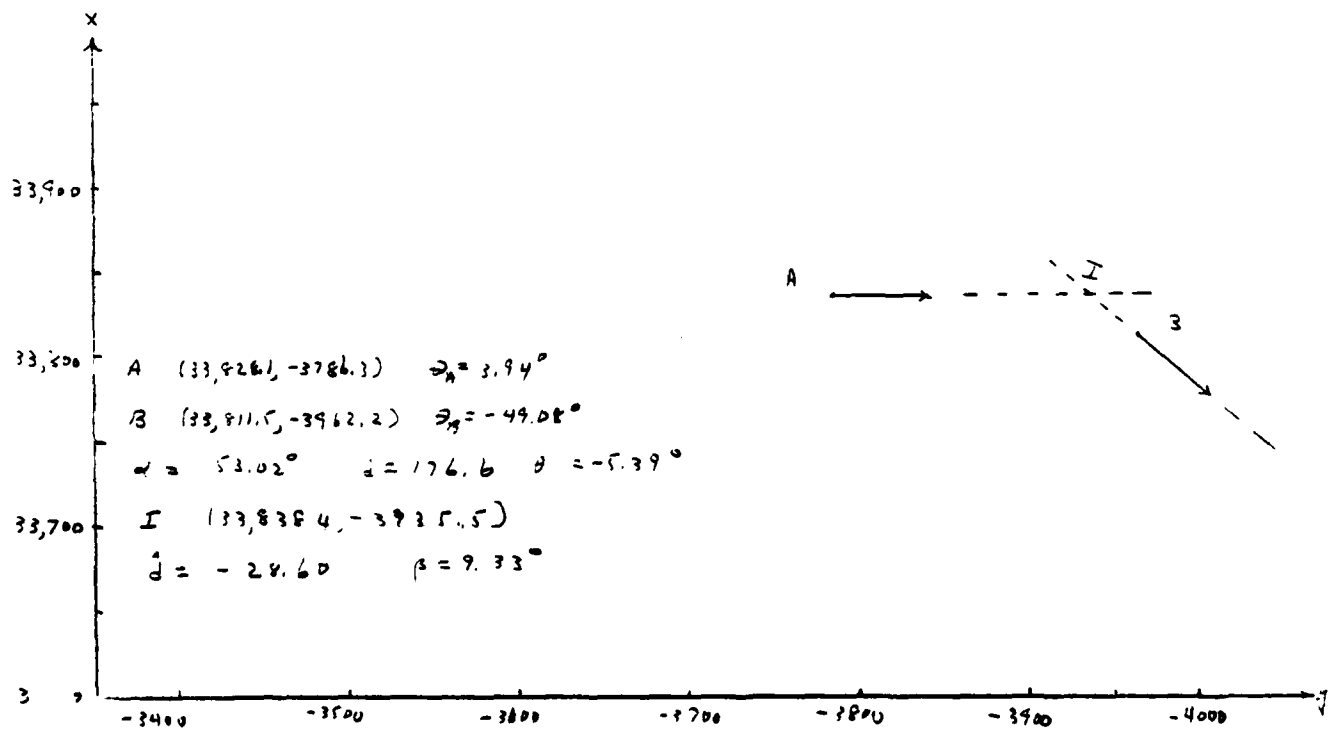



Figure 4h. 2I1H, 2129

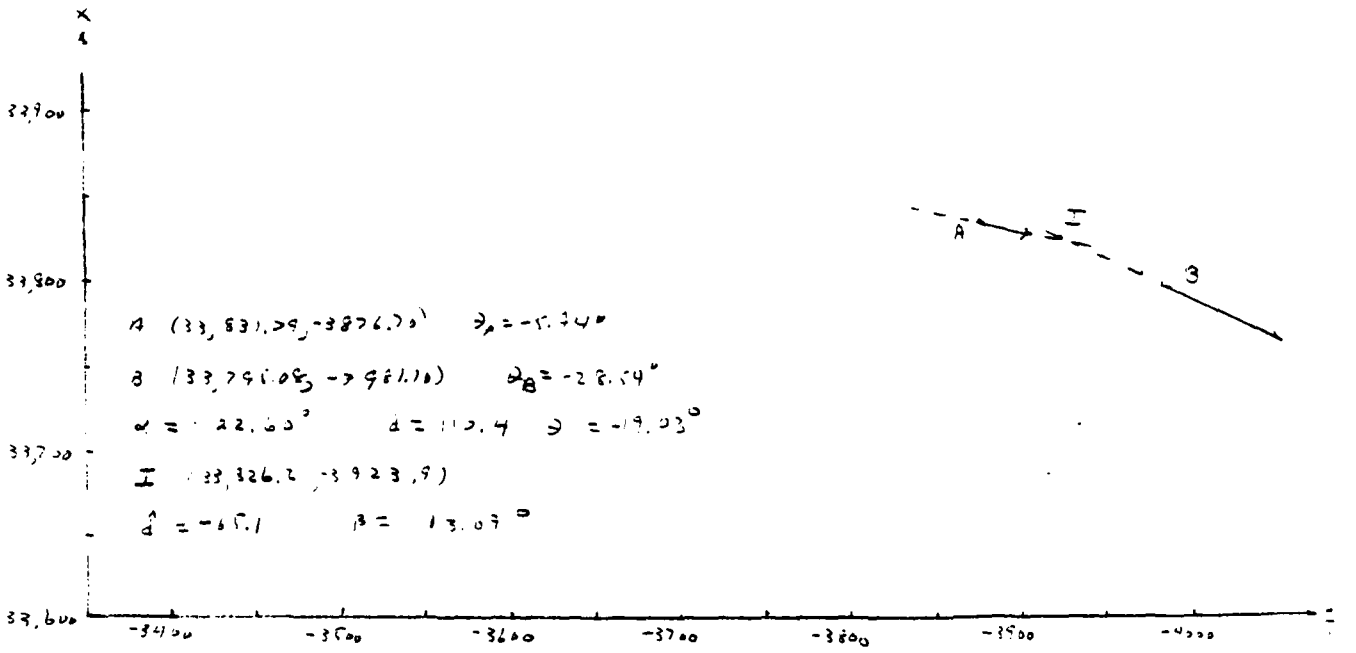



Figure 4i. 2I1H, 2130

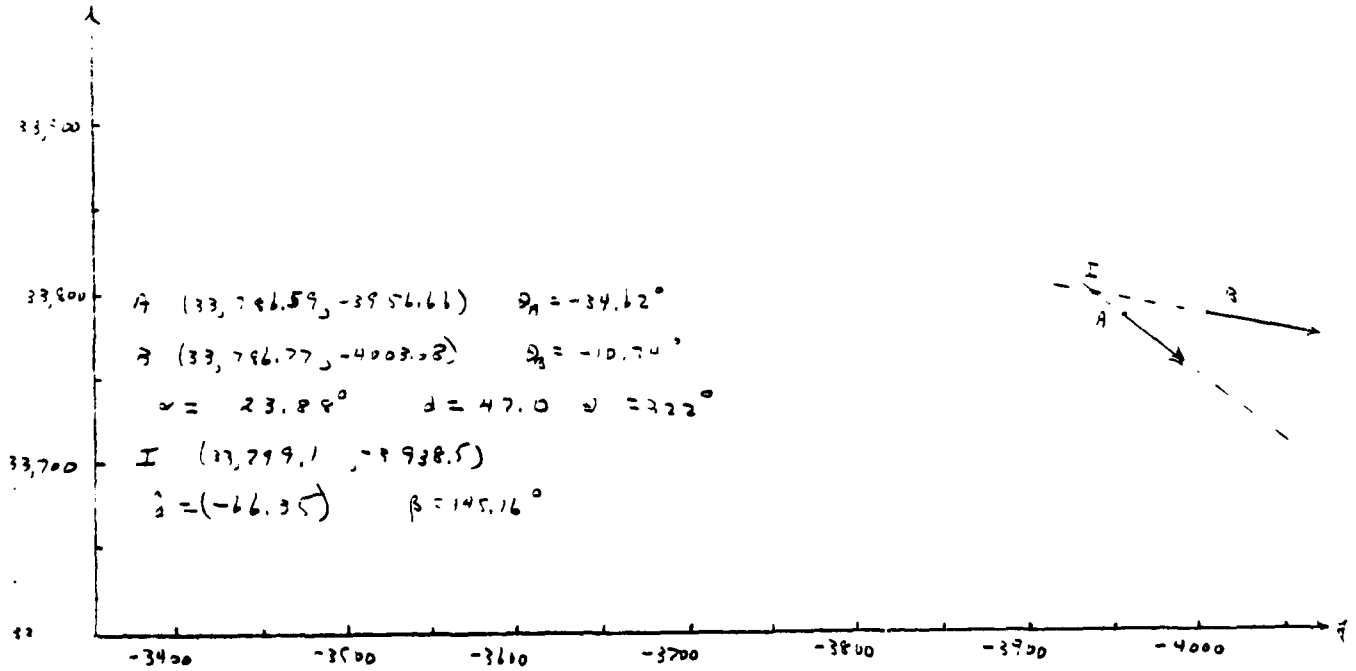



Figure 4j. 2I1H, 2131

C. Second Attack (2I2)

This attack was initiated at approximately time t = 2180 (see Fig. 3a). The portion of the attack in the vicinity of intercept is shown in Figure 5a and 5b. The geometry of the vehicles in this vicinity are shown in Figures 5c-ℓ. Again, actual intercept was not achieved since the attack was aborted in the vertical direction at about time t = 2199 when the attack vehicle was still about 364 feet from the target vehicle (see Fig. 5b and 5g). Actual crossing of the vehicular paths occurred at about time t = 2201 (see Fig. 5i) although discontinuance of the attack in the horizontal plane was not apparent until t = 2203 (see Fig. 5k) when the attack vehicle appears to have initiated the next search cycle (see Fig. 5a, also Fig. 3a). The smallest distance was about d = 117 and occurred at about time t = 2204.

The only missing points in this attack were the scheduled ones (every eighth point). The only potential outlier in the horizontal plane occurred in the target path after the attack was broken off. The potential outliers in the vertical plane of the attack vehicle path present a more serious problem (see Fig 5b). These will be examined in a separate report.

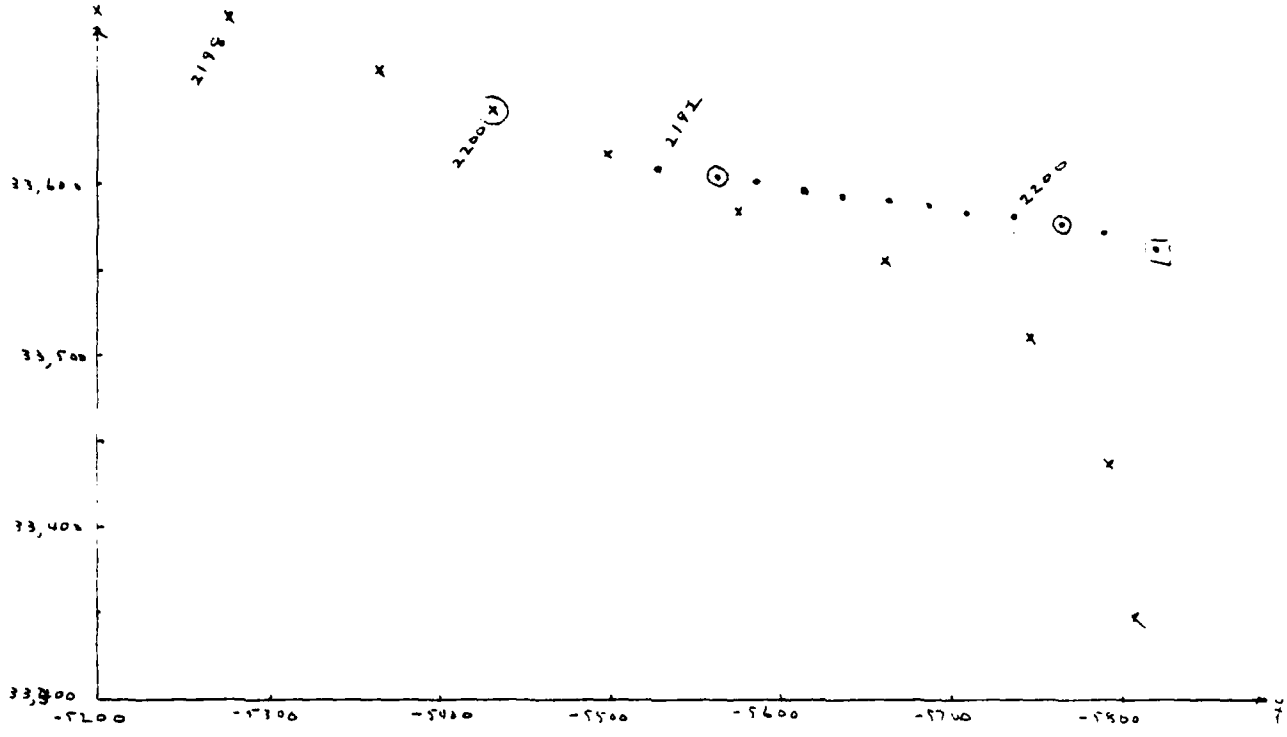


Figure 5a. 2I2H

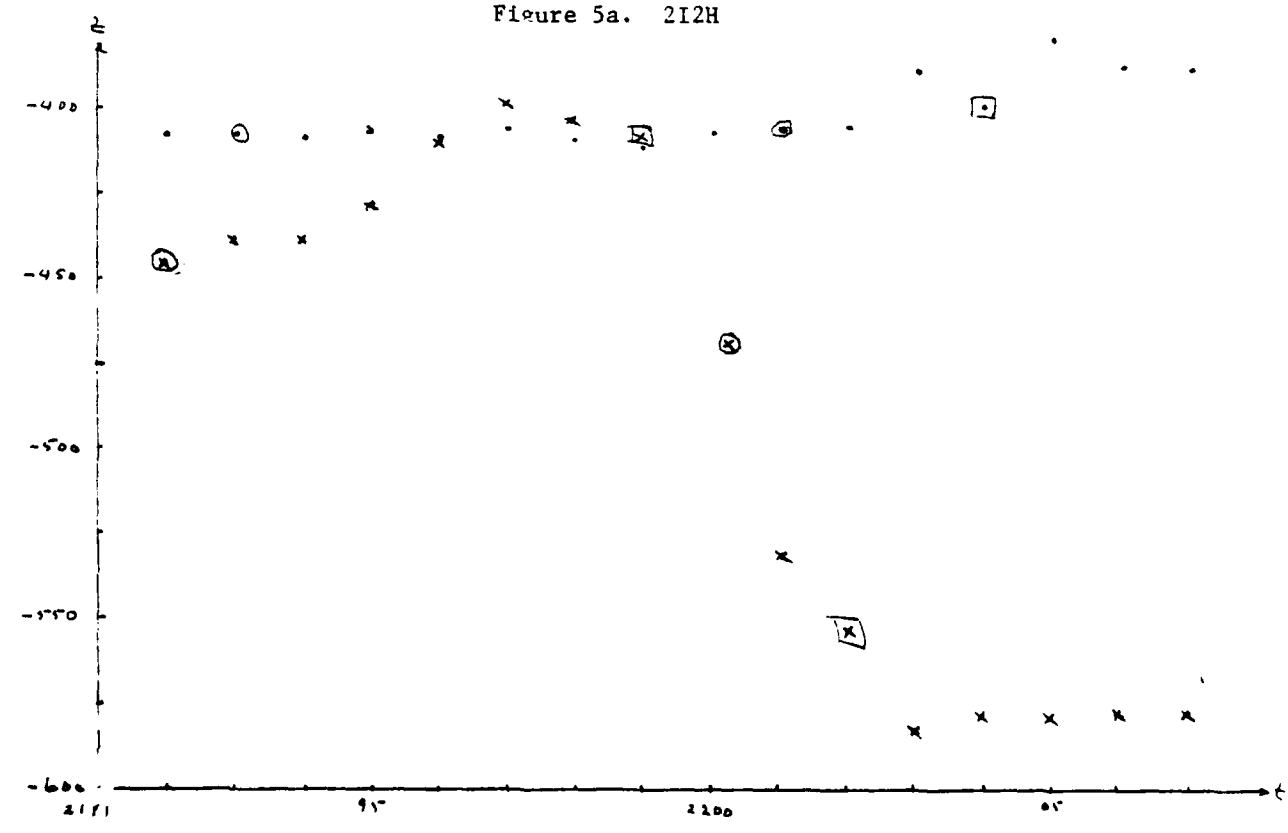


Figure 5b. 2I2Z

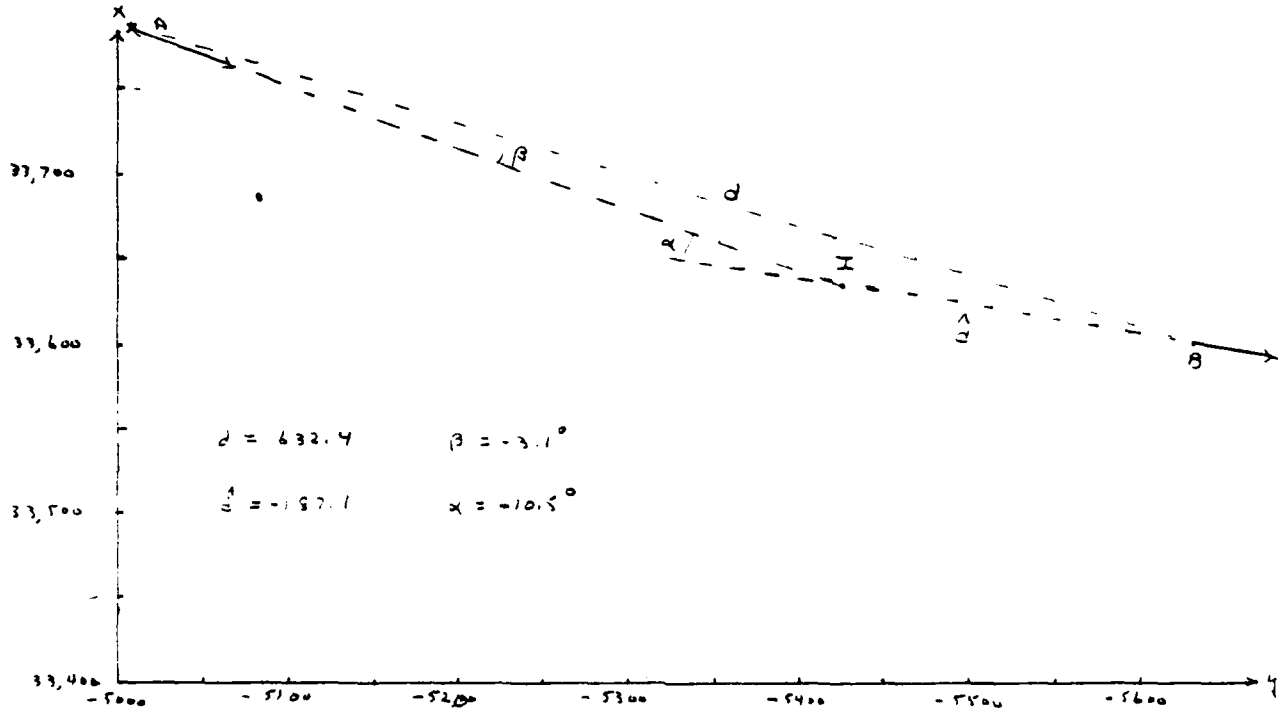



Figure 5c. 2I2H t = 2195

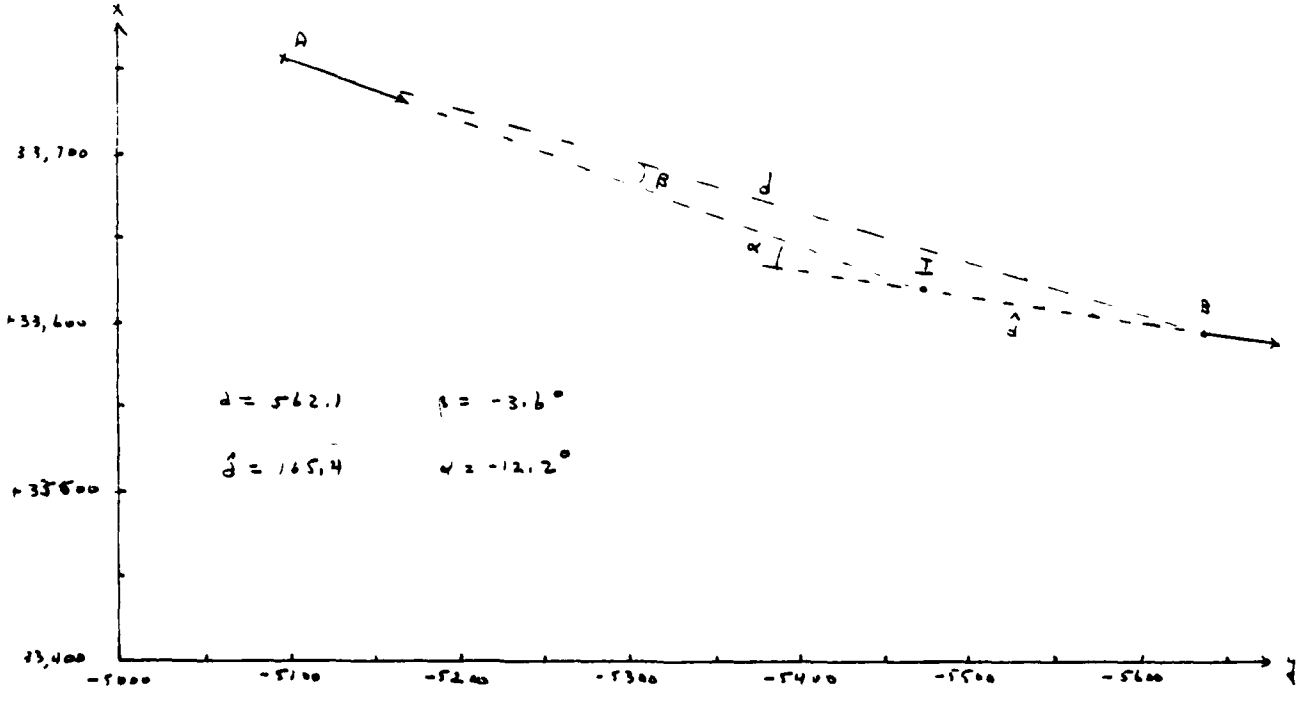



Figure 5d. 2I2H t = 2196

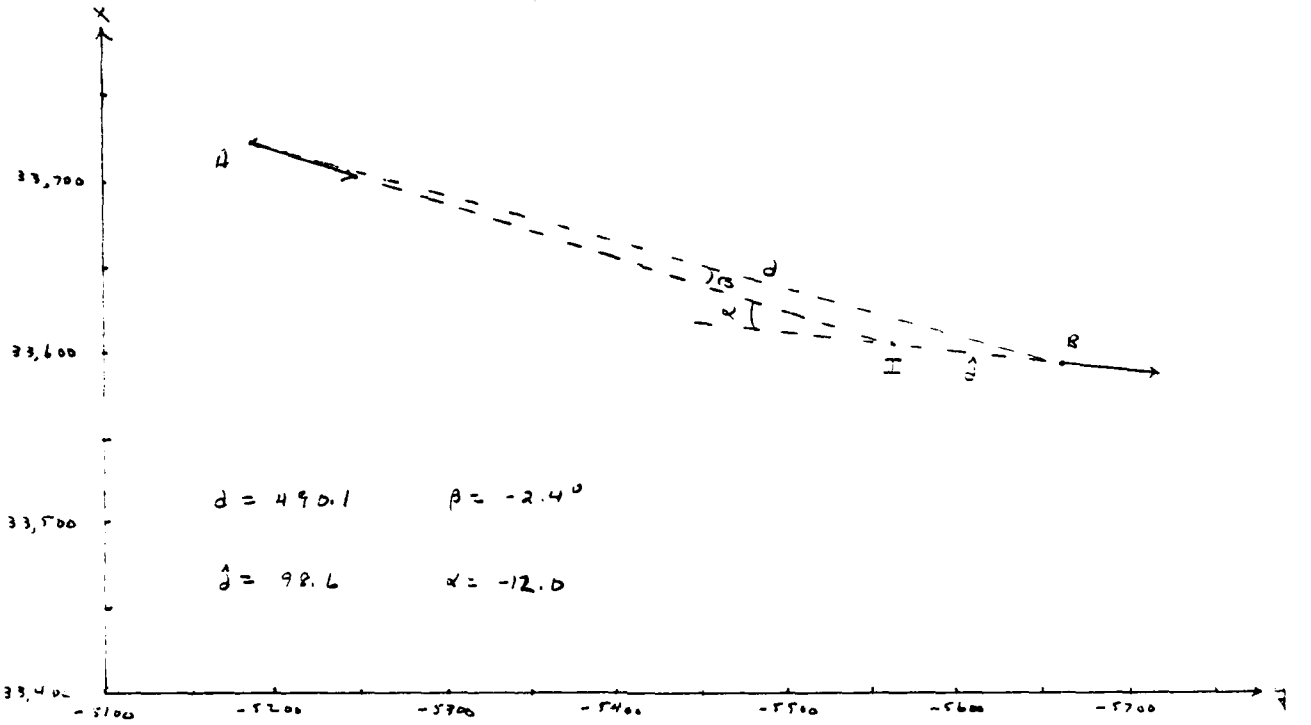



Figure 5e. 2I2H t = 2197

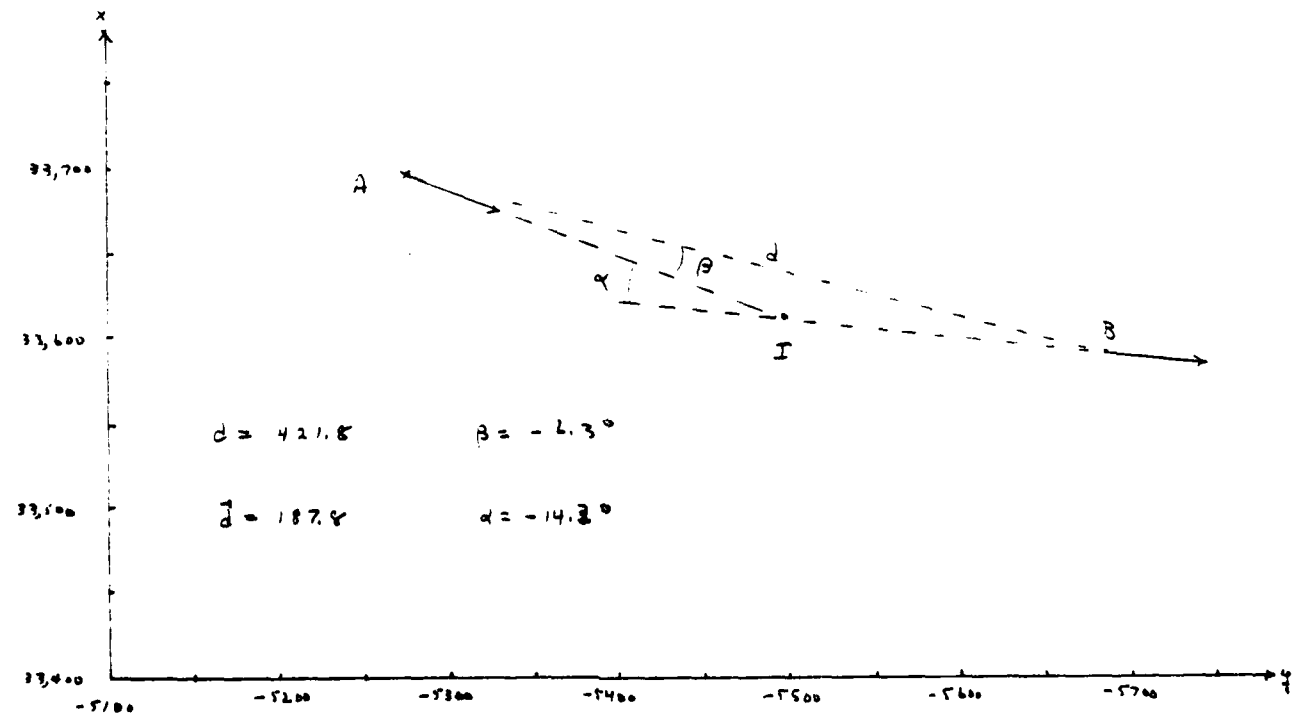



Figure 5f. 2I2H t = 2198

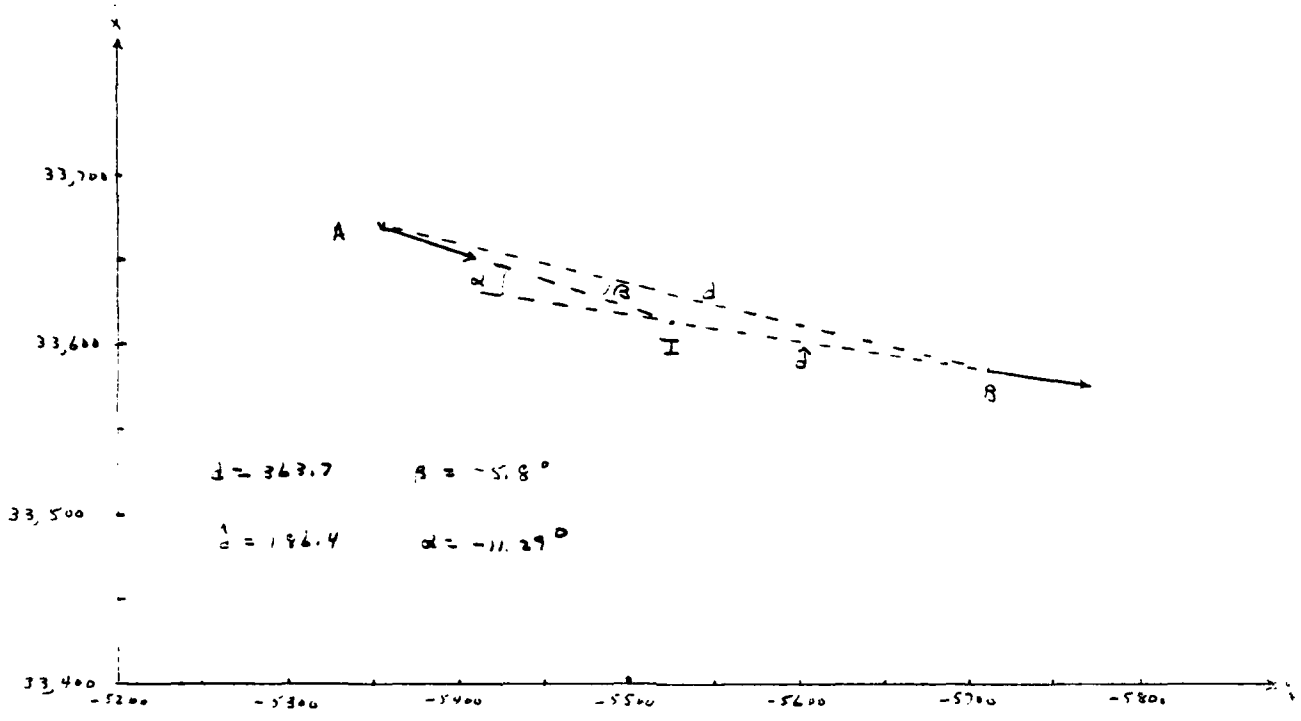



Figure 5g. 2I2H t = 2199

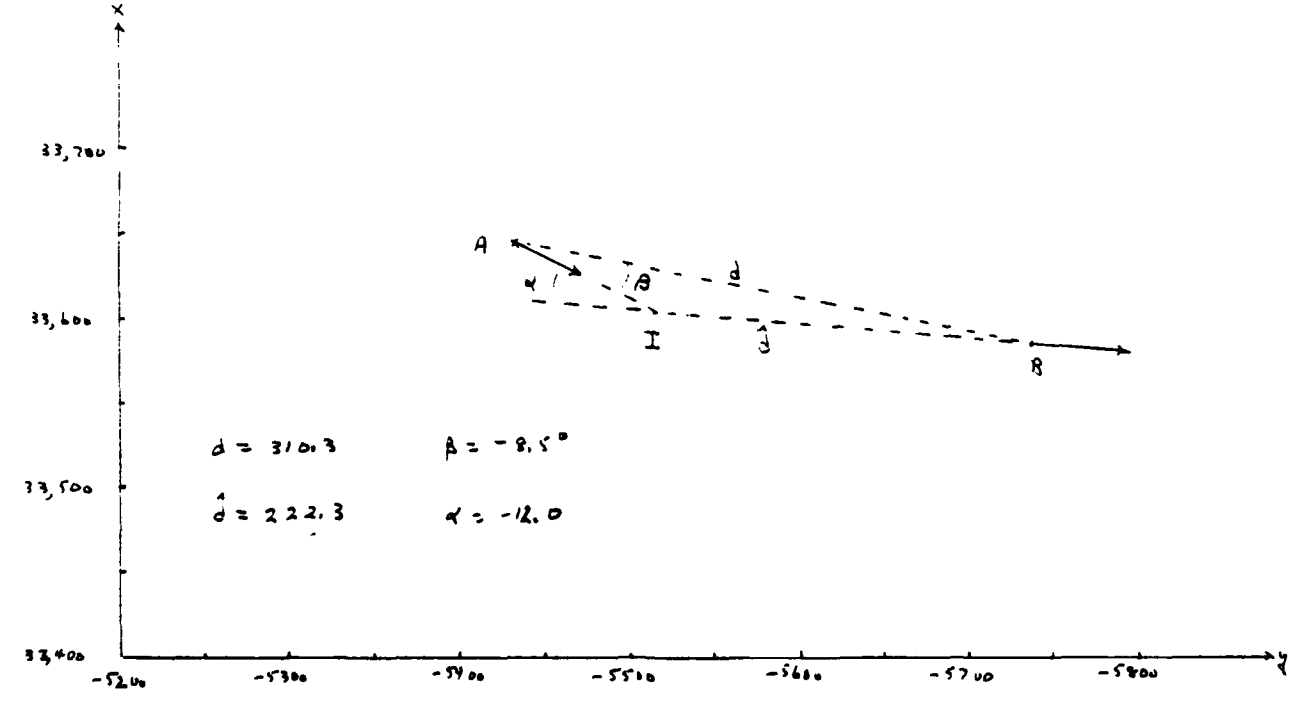



Figure 5h. 2I2H t = 2200

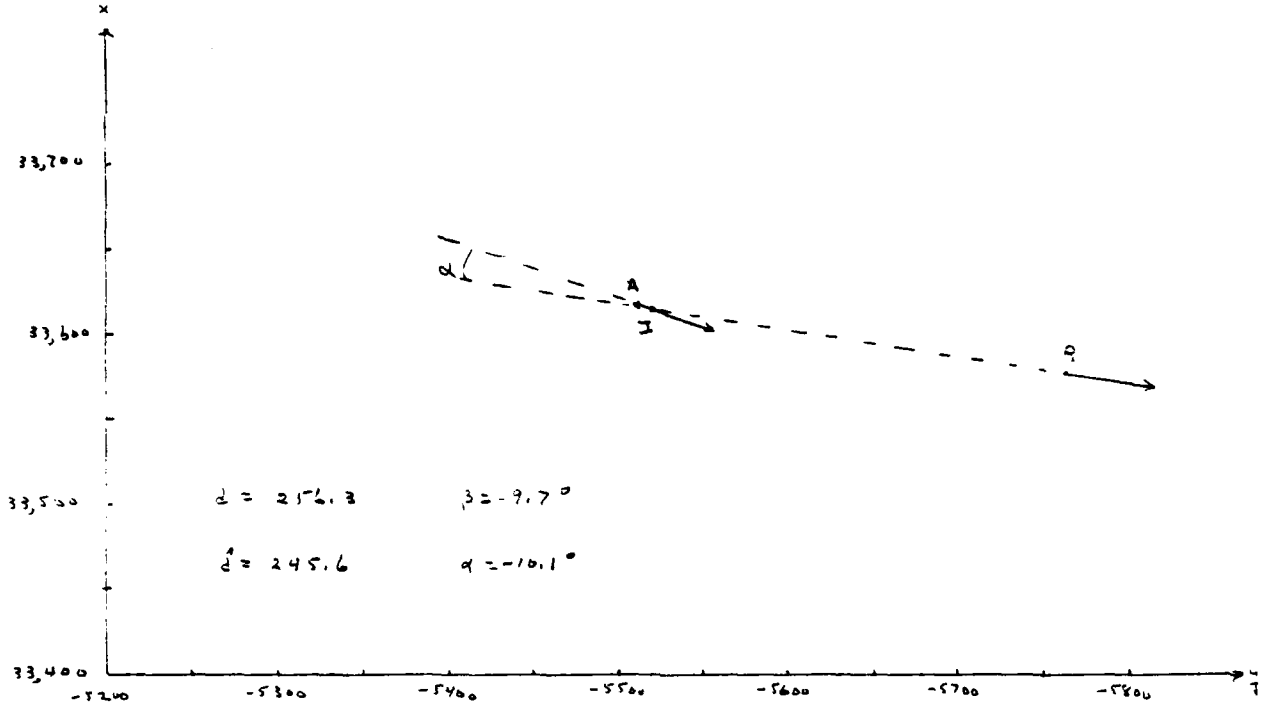



Figure 5i. 2I2H t = 2201

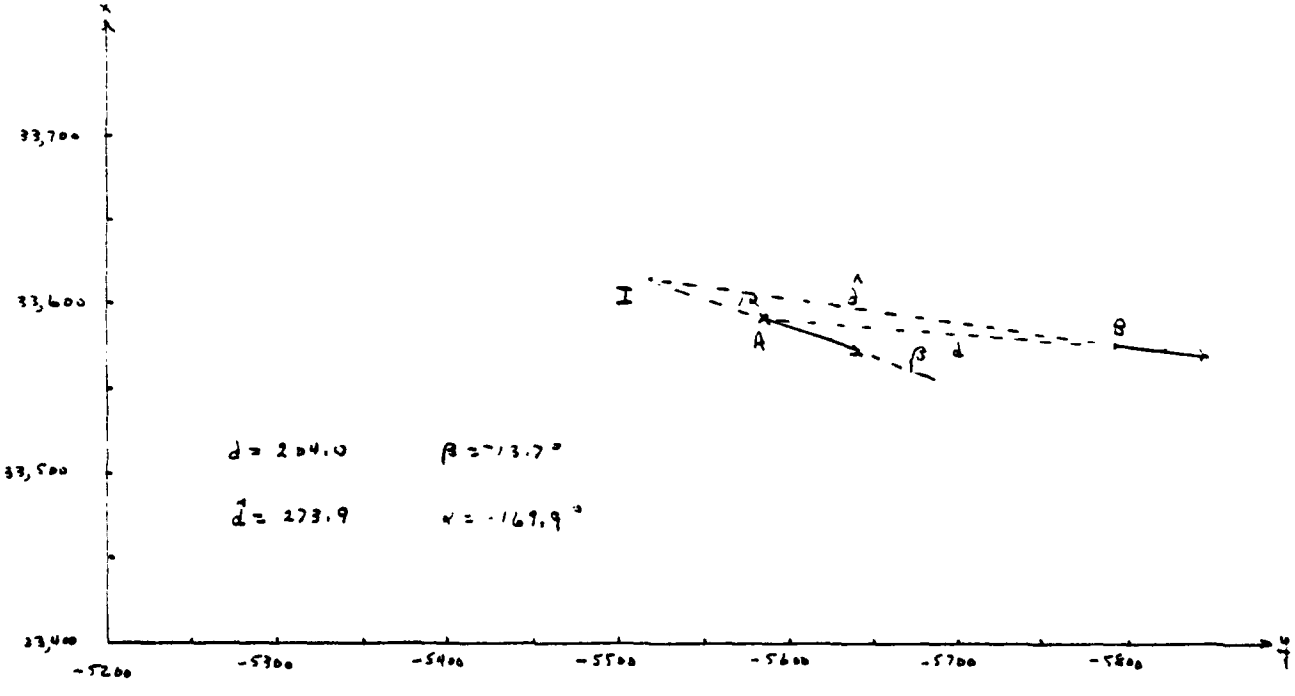



Figure 5j. 2I2H t = 2202

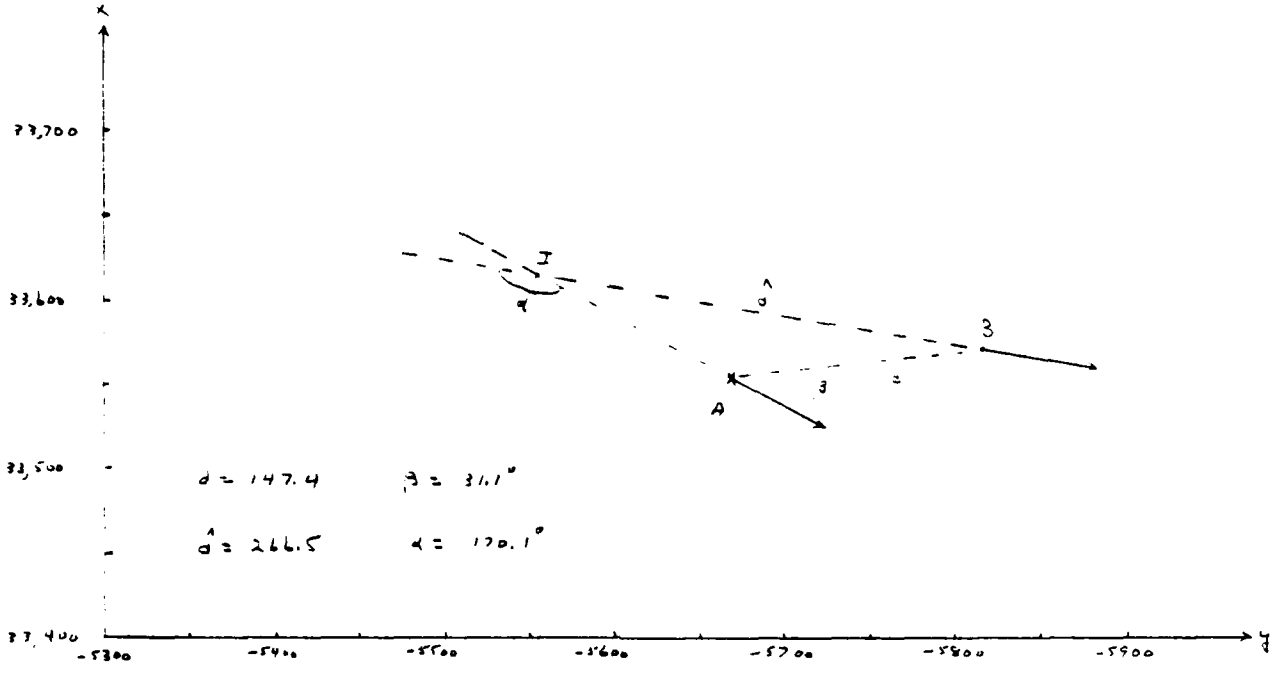



Figure 5k. 2I2H t = 2203

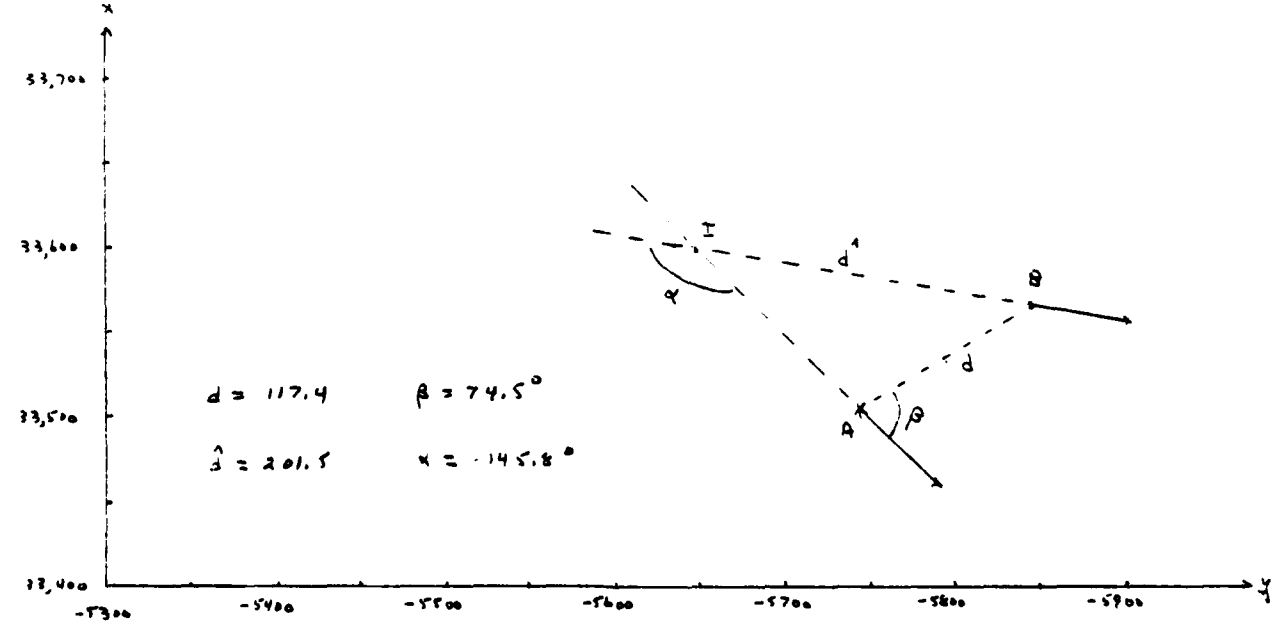



Figure 5ℓ. 2I2H t = 2204

D. Third Attack (2I3)

This attack was initiated at approximately time t = 2250 (see Fig. 3a). The portion of this attack in the vicinity of intercept is shown in Figure 6a and 6b. The geometry of the vehicles in this vicinity are presented in Figures 6c-j. As in the previous attacks, actual intercept was not achieved with the attack being aborted in the vertical direction at about time t = 2168 (see Fig. 6b) when the vehicles had a separation of d = 431.5 (see Fig. 6f). Discontinuance of the attack in the horizontal plane was not apparent until about time t = 2272 when the distance between the vehicles was about d = 215.5 (see Fig. 6j). The smallest distance between the two vehicles in the horizontal plane occurred at about time t = 2273 when it was d = 177.4.

Missing points (other than the scheduled ones) occurred only in the target path and only after the attack was completed. Three potential outliers were noted. The one of greatest concern was in the vertical component of the attack vehicle path at time t = 2268. Subsequent analysis is expected to confirm that this is indicative of the change in the attack vehicle path when the attack was aborted rather than an actual outlier (wild data point). (See Fig. 6b).

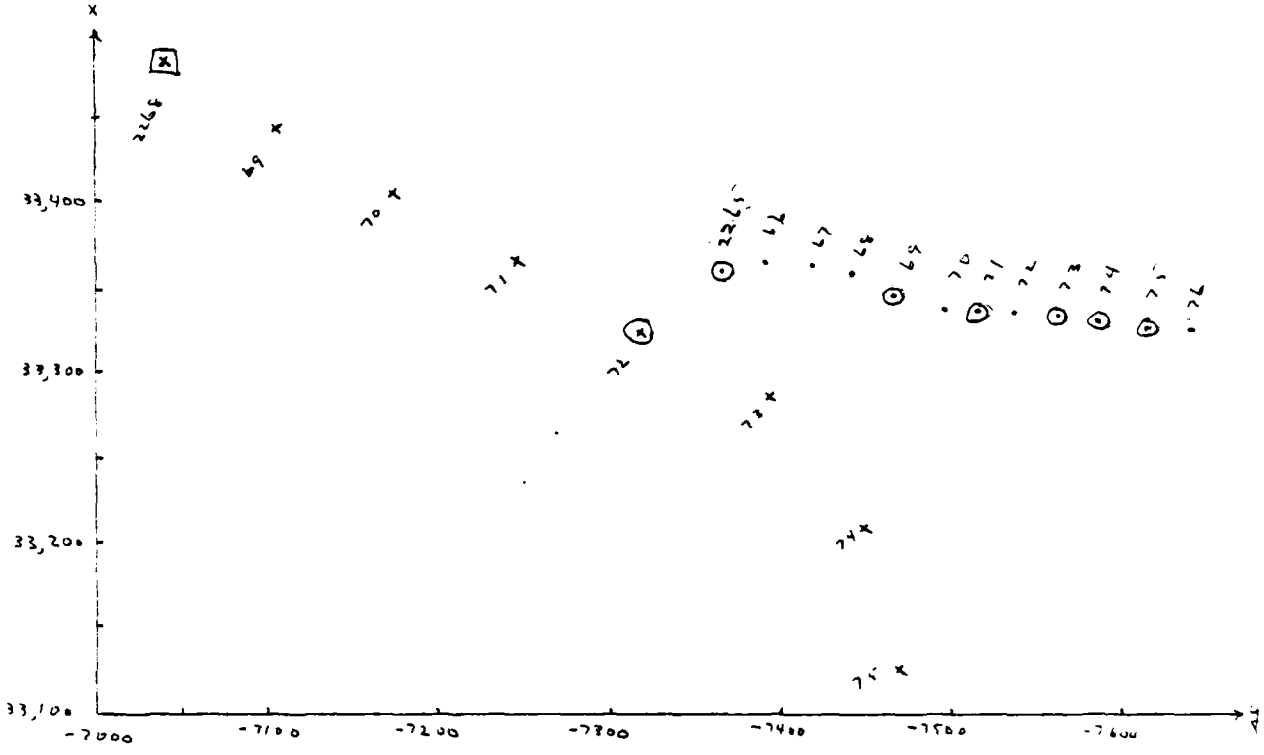



Figure 6a. 2I3H

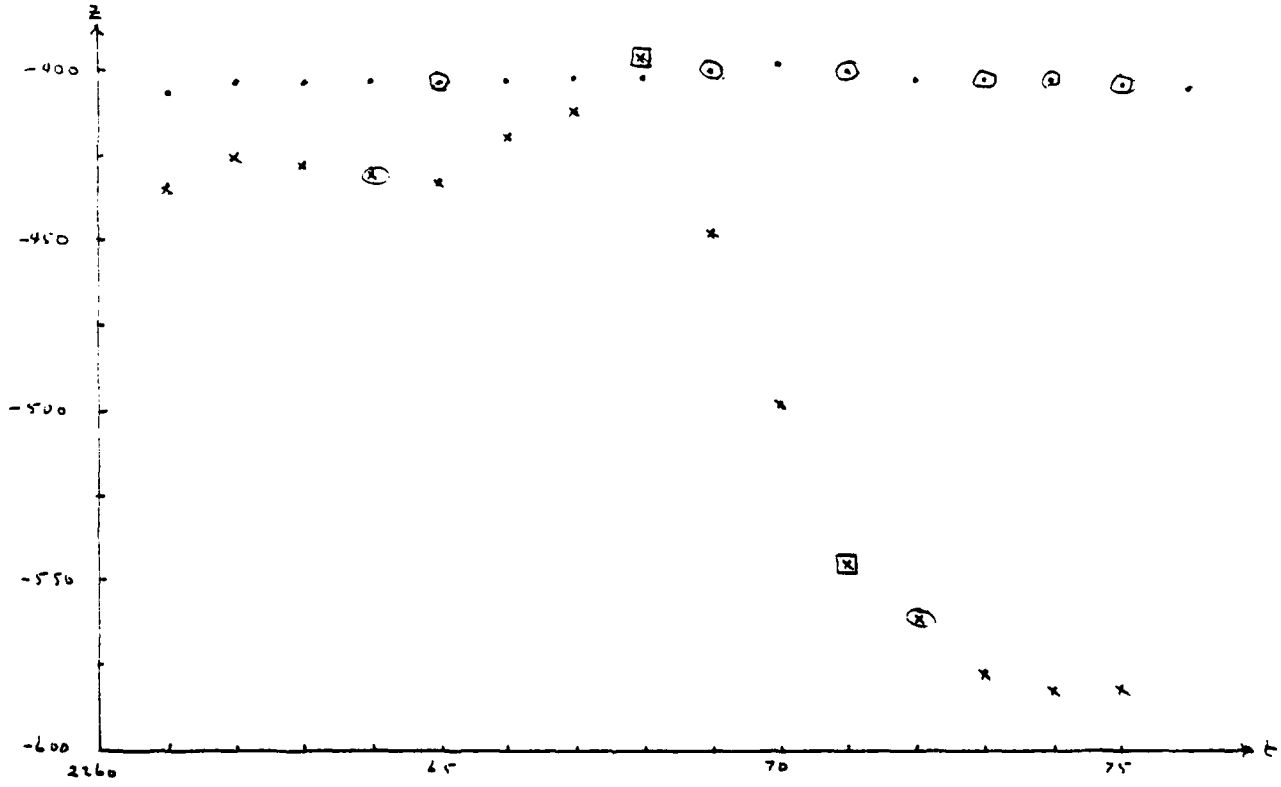



Figure 6b. 2I3Z

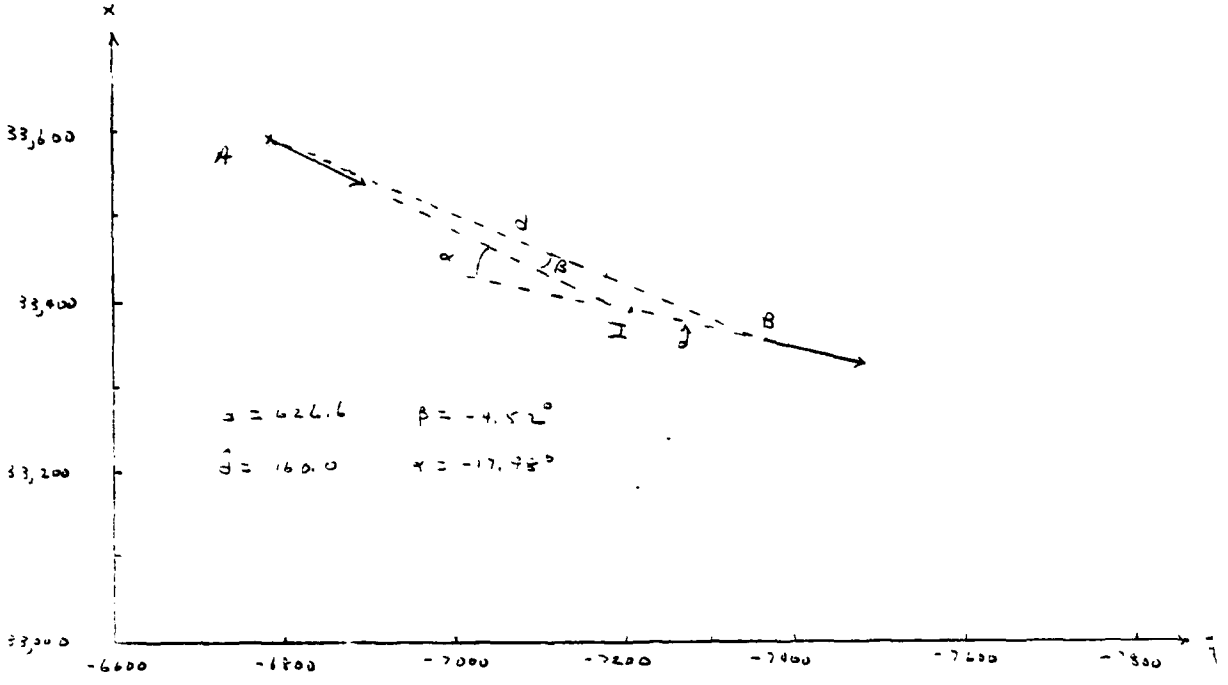



Figure 6c. 2I3H t = 2265

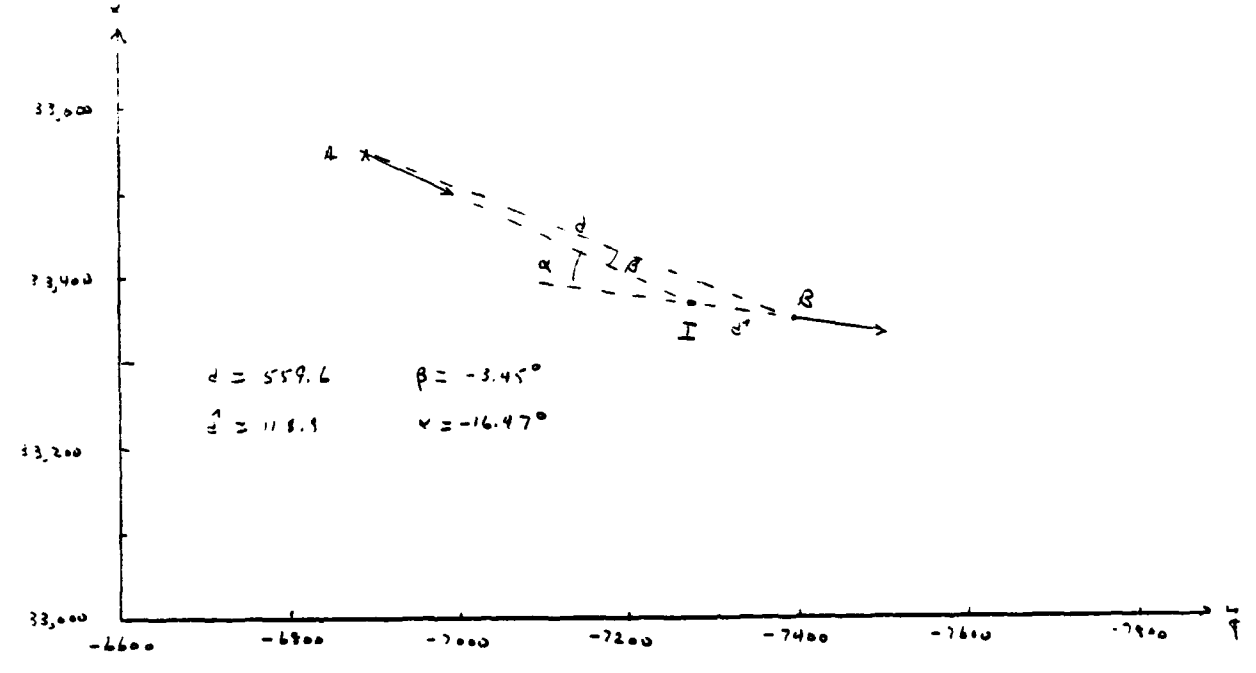



Figure 6d. 2I3H t = 2266

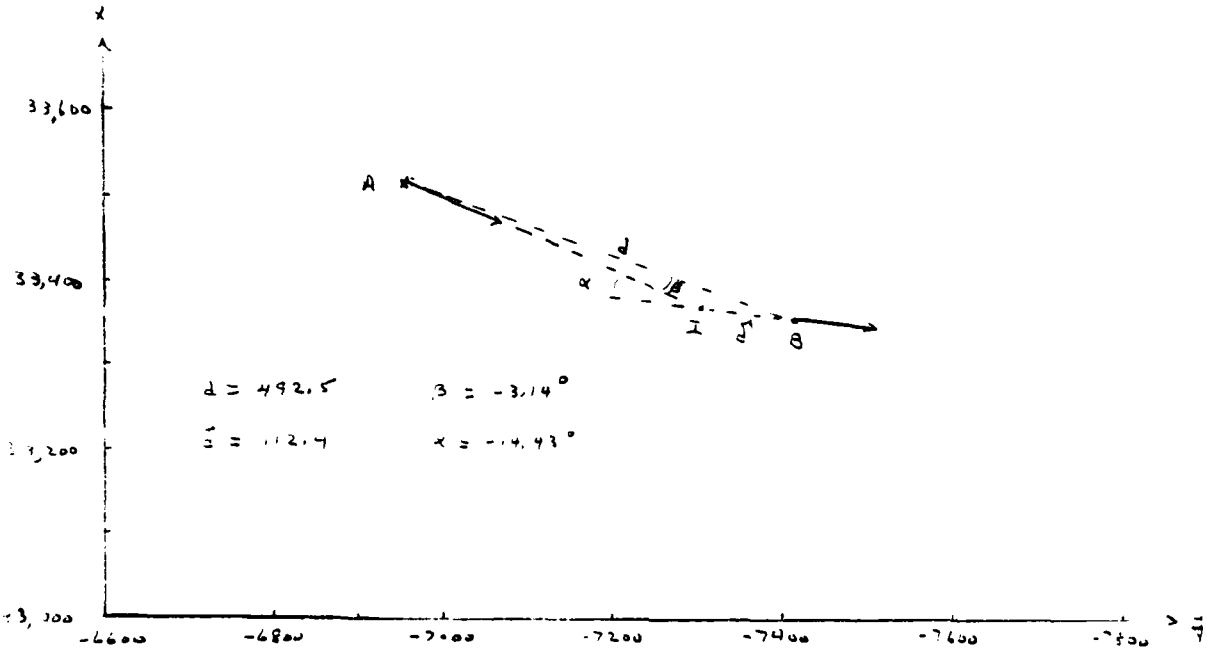



Figure 6e. 2I3H t = 2267

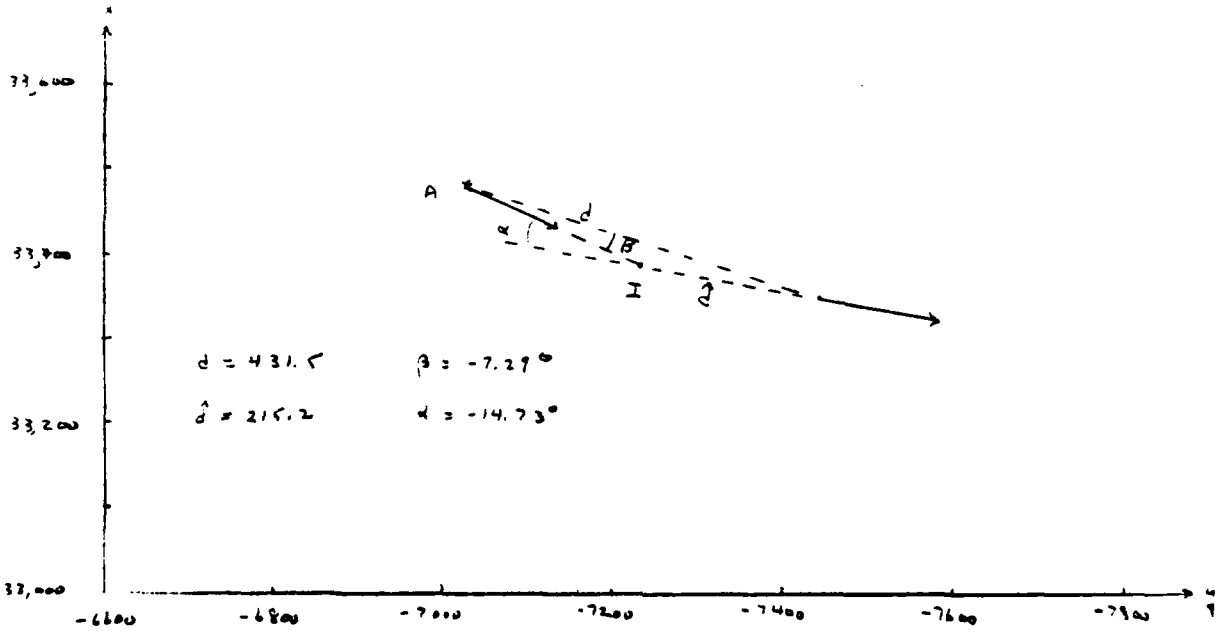



Figure 6f. 2I3H t = 2268

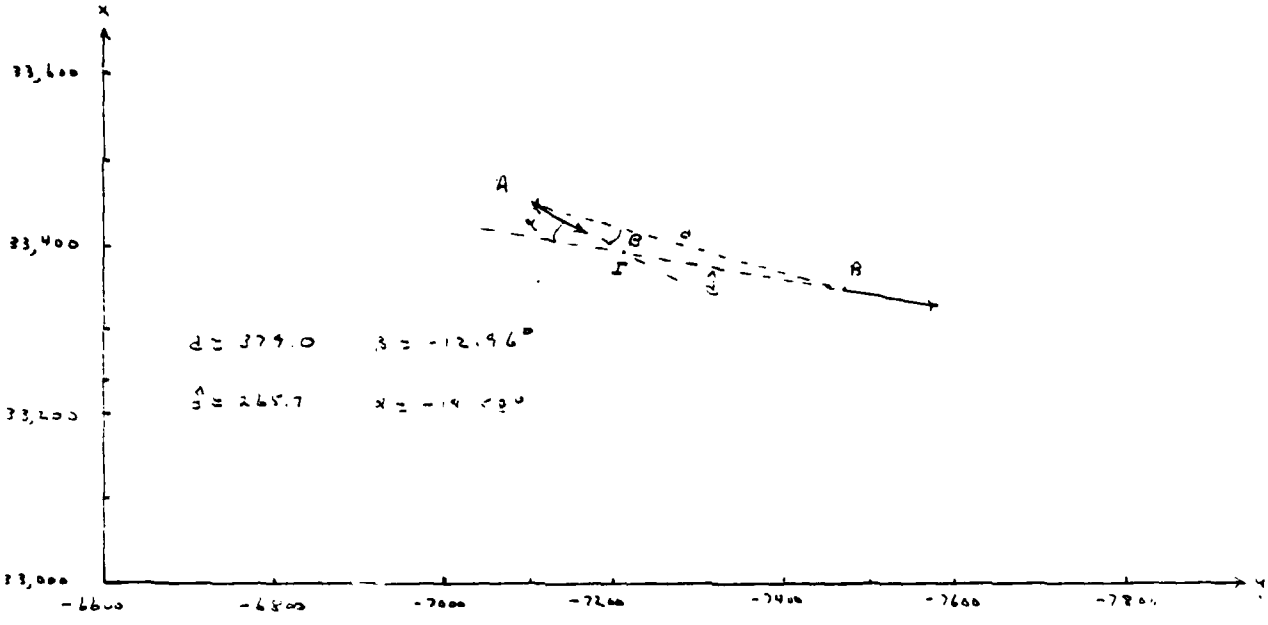



Figure 6g. 2I3H t = 2269

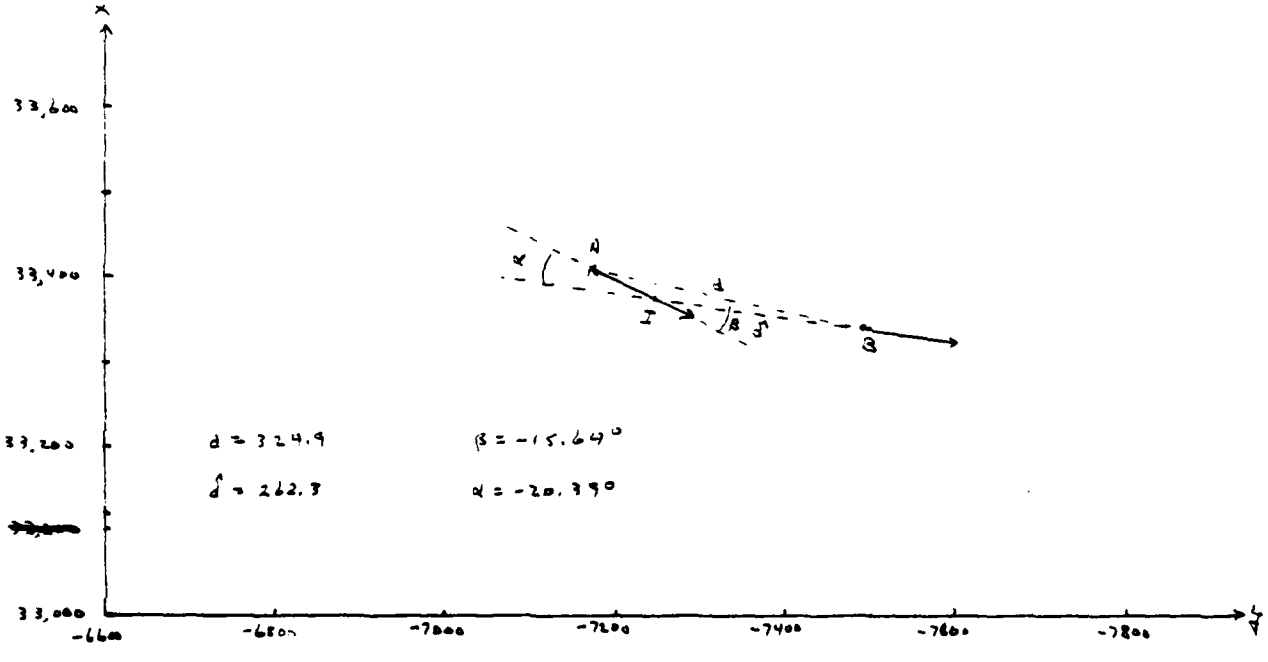



Figure 6h. 2I3H t = 2270

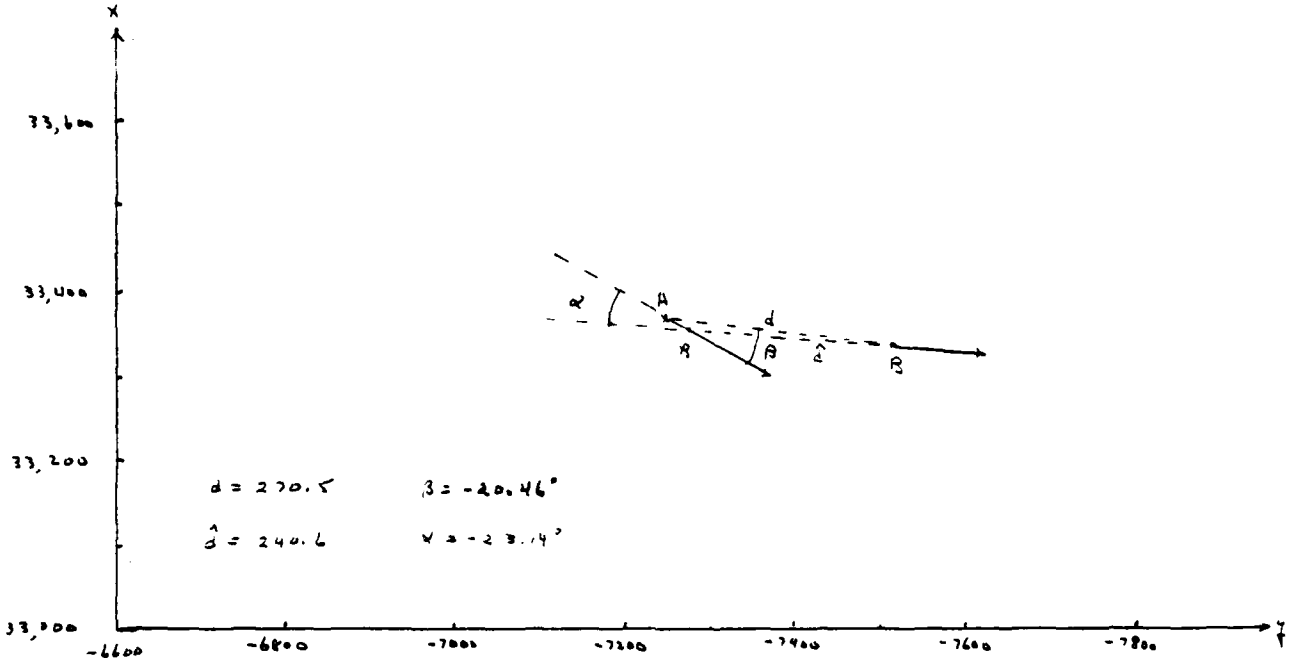



Figure 6i. 2I3H t = 2271

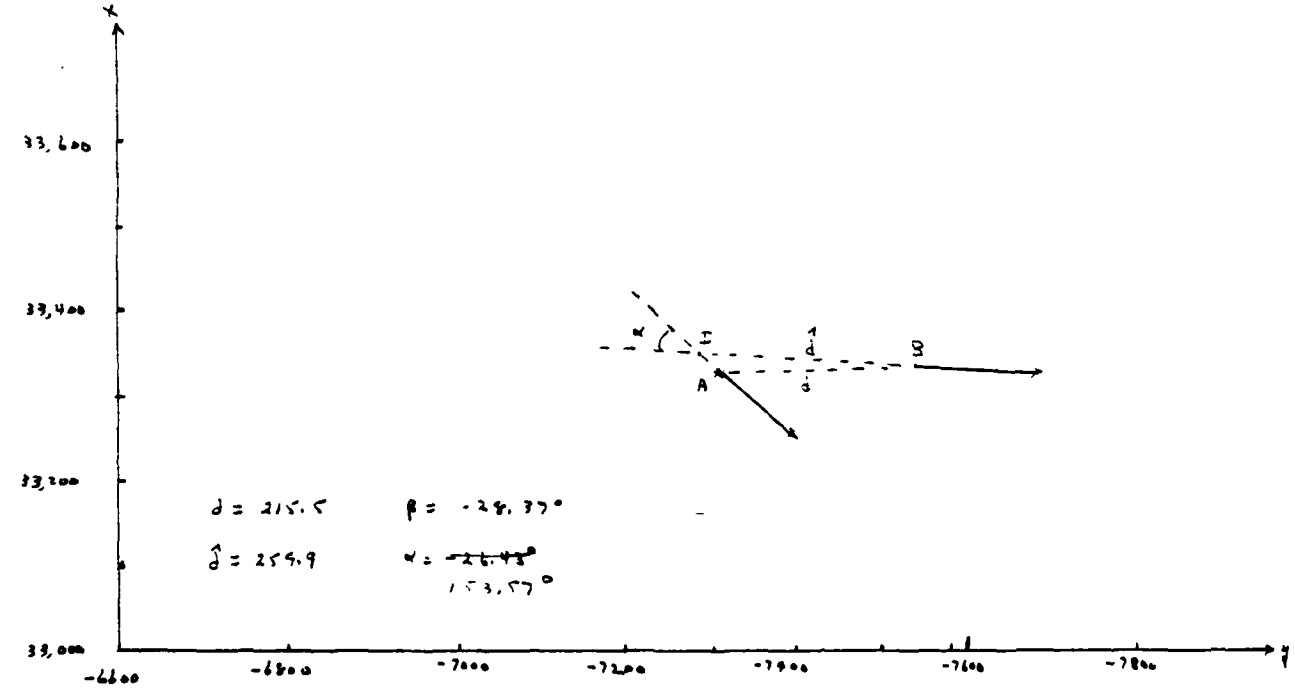



Figure 6j. 2I3H t = 2272

## IV. CONCLUSIONS AND RECOMMENDATIONS

The analysis presented in this report could be of value in assisting anyone concerned with details of what actually occurred in an attack by a vehicle on a moving target vehicle. In case an intercept actually occurs, the point and angle of impact can be of use in damage assessment. When an intercept is not achieved, the miss distance (smallest distance between the vehicles) could be of interest. For example, when the attack vehicle crosses the target vehicle's path behind the target vehicle, examination of the geometry could be of assistance in determining whether the target vehicle was actually attacking the disturbance in the wake of the target vehicle instead of the target vehicle itself.

Incorporation of figures such as Figure 3a-j into a program for processing 3-D data would require computer graphics. Incorporation of such graphics at all observational times would result in an undesirable volume of computer output. Restriction of the graphics to the vicinity of intercepts would be preferable but would require identification of these vicinities. One possible alternative procedure would be the reservation of special intercept graphics to intercepts of special interest identified by a user of the general data smoothing output as a separate subroutine not included in the general data smoothing program.

There are several aspects of the intercept problem which have not been covered in this report and need further examination. Three of these are:

1) Geometry of the vertical components in the vicinity of intercept has not been completed. This should be developed and included in the program. For example, vertical attack angle and miss distance need to be considered as well as horizontal attack angle and miss distance to determine actual attack angle and miss distance.

2) Treatment of ponts indicated as potential outliers by the sequential differences procedure should be examined in more detail (Ref. 2). Thus, for example, potential outliers are identified in the vertical components of the attack was aborted in the vertical direction and should be interpreted as signifying a change in path rather than a wild observation. (Such a change in path can be expected when an attack results in intercept and the geometry at this point is of special concern.) Examination of some of the potential outliers in this trial run and the contamination of their treatment by neighbouring missing points warrants further treatment and should be considered in a separate report.

3) Coincidence of observational times with times of greatest concern for vehicular geometry (i.e., intercept point) cannot be expected. Some capability for interpolation between observational times may be of some interest.

## References


1. J. B. Tysver, "Smoothing 3-D Data for Torpedo Paths", Naval Postgraduate School Technical Report NPS55-78-036Pr, May 1978.

2. J. B. Tysver, "Use of Sequential Differences in Smoothing 3-D Data", Naval Postgraduate School Technical Report NPS55-79-012Pr, May 1979.

3. J. B. Tysver, "A 3-D Data Smoothing Algorithm", Naval Postgraduate School Technical Report NPS55-81-001, January 1981.

4. J. B. Tysver, "Selection of Segment Length for Least-Squares Polynomial Smoothing", Naval Postgraduate School Letter Report, January 1982.

DISTRIBUTION LIST

| | No. of Copies |
|---|---|
| Commanding Officer<br>Naval Undersea Warfare Engineering Station<br>Keyport, WA 98345 | |
| Attn: Mr. R. L. Marimon, Code 70 | 2 |
| CDR Brian Uber, Code 80 | 2 |
| Mr. R. L. Mash, Code 50 | 2 |
| Mr. S. McKeel, Code 51 | 1 |
| Mr. David L. Sparke, Code 5122 | 2 |
| Mr. Paul R. Hughes | 2 |
| General Administration, Code 0115 | 1 |
| Naval Postgraduate School<br>Monterey, CA 93940 | |
| Attn: Dean of Research, Code 012A | 1 |
| Library, Code 0142 | 4 |
| Professor O. B. Wilson, Jr., Code 61W1 | 1 |
| Professor J. B. Tysver, Code 55Ty | 7 |
| Professor R. R. Read, Codd 55Re | 1 |
| Professor J. D. Esary, Code 55Es | 1 |
| Professor H. A. Titus, Code 62Ts | 1 |
| Professor D. A. Stentz, Code 62Sz | 1 |
| Dudley Knox Library<br>Code 0142<br>Naval Postgraduate School<br>Monterey, Ca 93940 | 4 |


ATE
LME